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THE DEVELOPMENT OF A FREIGHT DISTRIBUTION MODEL FOR CONNECTING INTER-ISLAND FREIGHT TRANSPORT

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ABSTRACT

Inter-island freight transport costs in eastern compared to western Indonesia are relatively high, caused by operator charges for roundtrip fees. In order to make the distribution of freight efficient, the network of freight transport needs to be rationalized on a regional basis. The output from the regional model counts are few and far between in relation to intercity traffic volume data, and the disaggregate model at a regional level requires more effort in conducting travel route surveys. Therefore, aggregated analysis is preferable initially, based on the traffic volume and the commodity flow for inter-island freight transport. The accessibility and connectivity of the land use can be obtained from the freight distribution model as a measurement to evaluate different land use scenarios and also to provide feedback for land use modeling, as a parameter for freight location choice. With a freight distribution model to identify freight commodity supply and demand in a particular region, potential freight transport generation uses such variables, which consider generalized transport costs. Using the Furness and Maximum Entropy models, the results indicate that Furness model finishes in the 4th iteration and Maximum Entropy in 6th, while the negative exponential function offers the best calibrated estimation, using sea freight movement data. It was also found that the positive value of β means that any increment of travel time decreased the rate of freight flow, which mirrored the conditions in reality: the higher travel costs, the fewer the number of flows between zones. The data is analyzed in the context of modeling intra-city freight flow in the archipelagic region of northern Maluku.

Keywords: Freight distribution; Impedance function; Synthetic model; Transport cost

1. INTRODUCTION

Freight transport becomes the major instrument for the inter-island movement of goods between cities in an archipelagic country like Indonesia. With continuing economic growth of 5 percent on average, transport demand is becoming a critical issue that influences the performance of transport activities (Wang et al., 2013). This fact substantiates data concerning the change in land use, which causes a lack of spatial coordination between transport demand and transport facilities. Hence, coordinated development of land use and transport facilities is required for regional planning (Waddell, 2002).

The first transportation model in Indonesia was based on the travel survey undertaken in 1992.

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After 2000, the model was improved, using a traditional four-step model (including trip generation, distribution, modal choice and traffic assignment), which is applied to regional urban transportation planning. Furthermore, the four-step model considers aggregate destination choice and mode choice models for improving the forecasting data accuracy. At present, the freight transport demand model is also developed based on the traditional trip-based model with various compositions and structures (de Jong et al., 2004). These integrated regional planning models are still in progess in terms of research domain.

Inter-islands freight transport in an archipelagic region is influenced by the level of population and economic activity, trade, agriculture and industry. Other factors which are identified as being significant in generating freight transport demand include population, GRDP, GRDP per capita, proportion of industrial sector products, production surplus, and deficit (Holguin-Veras et al., 2010). Accuracy of population data and socioeconomic planning on a regional scale is an important factor in transportation planning for the movement of goods. Transportation planners are intimidated by the lack of data whenever they embark on a project involving freight movement, whether on a national, statewide or regional scale (Mitra & Tolliver, 2009). Various types of transportation exist for the movement of goods from their origin to destination. The transfer from land and sea modes may occur in the movement of freight between the islands. However, modeling of a freight system is a very difficult task because of its complexity, since freight movement involves complicated linkages among many freight agents interacting in various supply chains (Wisetjindawat et al., 2006). The great variety of public data sources is another complication (Rwakarehe et al., 2014).

With this background, this study attempts to set out modeling intra-city freight flow in the archipelagic region of northern Maluku, while the primary interest was to contribute to the knowledge and literature on using such models for freight distribution modeling. Another objective was to compare and evaluate the accuracy, applicability and generality of such freight distribution models in a complex real-world case. For this purpose, a Doubly Constrained Gravity (DCGR) model was established as the benchmark, with various impedance functions, such as a deterrence factor against which model performance was evaluated empirically using the 2011 regional freight travel survey data.

2. METHODOLOGY

Firstly, this model is composed of multiple components covering regional inter-island areas. Aggregate methods are usually used in DCGR model. This framework accommodated a modified four-step model with specificity according to identifiable targets. A proposed framework for integrated land use and a suitable and feasible transportation model for regional use was adopted (Wang et al., 2013).

Northern Maluku regional zones (Figure 1) and the potential freight generated were determined by using the Indonesian national origin-destination (OD) survey dataset shown in Table 1, and also considering the cost matrix, together with total trip ends to estimate the parameters FO_i and FD_j. The main objective of this test is not only to see how good the proposed estimation methods are in estimating the parameters of the given transport models and OD matrices, but also to see how good the estimated OD matrices are compared with the original matrices.

A synthetic model and friction factor was adopted which used and compared sets of the Furness and Maximum Entropy models and the result was an estimation model for commodity flow in tons (Tamin & Suyuti, 2007). These models accounted for only the loaded freight in the network using a 2006 OD Survey dataset. Time was used as a cost variable related to the impedance because actual costs were not available at that time.

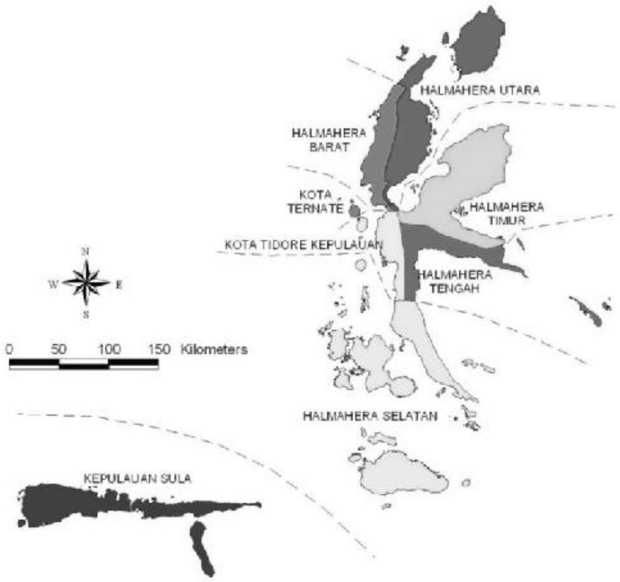

Figure 1 Zoning cordon system (North Maluku Province of Indonesia)

Table 1 Freight generation of North Maluku 2006

Zone	Region	Production	Attraction
1	West Halmahera	31,200	35,047
2	Central Halmahera	123,423	135,139
3	Sula Island	8,494	8,392
4	South Halmahera	24,136	23,817
5	North Halmahera	30,918	28,777
6	East Halmahera	9,866	8,338
7	Ternate City	113,845	89,365
8	Tidore City	109,421	122,428

Source: National OD 2006 Survey

This data is shown in Table 2, which is also divided into 8 administrative zones. Three different impedance functions were used: negative exponential, power function (quadratic exponential) and tanner function.

The result of the calibration process can be used to estimate the future of freight traffic demand using the OD pattern and the forecasted volume for each zone.

Table 2 Cost matrix (C_{ij}) in minutes between regions of North Maluku

Zones	1	2	3	4	5	6	7	8
1	0	90	960	450	30	240	90	90
2	90	0	960	450	120	60	150	150
3	960	960	0	450	990	510	900	900
4	450	450	450	0	510	180	450	450
5	30	120	990	510	0	270	270	270
6	240	60	510	180	270	0	540	540
7	90	150	900	450	270	540	0	60
8	90	150	900	450	270	540	60	0

2.1. Method

This regional inter-island model is focusing on the movement of freight. The layer is partitioned to regional model zones according to boundaries of districts and provinces. Freight travels were estimated by regional travel surveys and the historical daily traffic volume by road, vessel and air. The data were studied by three types of Origin-Destination (OD) matrices: (1) External-Internal (EI) trips by freight entering the regional area from the outside; (2) Internal-External (IE) freight generated within an intra-regional area and distributed to another regional area; (3) bypass freight transport with stops in a regional area. Freight travels were estimated according to the commodity flow survey and the historical daily freight activities conducted by all kinds of transport modes. The commodity flows and related freight transportation activity are specific to each province.

The output from the regional model counts for selected data related to intercity traffic volume and the disaggregate model for the regional level requires more tasks to be defined in the travel survey. Therefore, aggregated analysis is preferred initially, based on the traffic volume and the commodity flows. The IE and bypass freight trips obtained in the regional model were used as input to time allocation directly and assigned to the intercity network. The EI freight trips are input to the intercity freight generation model and distributed with other intercity level trips.

2.1.1. Freight distribution model

Aggregate models are suggested for the freight demand model, because it is less complex and diverse than passenger travel models. The vehicle types are categorized as bulk vehicles and containers vessels (Mishra et al., 2013). Trip production and attraction rates for each region, employment types, and vehicle types are estimated from regression analysis. Then the gravity model is used for trip distribution, as shown in Equation 1 (Mishra et al., 2013).

$$T_{ij} = P_i \,.\, A_i \,.\, F_{ij} \,/\, \textstyle\sum_i (A_i \,.\, F_{ij}) \tag{1}$$

where, T_{ij} is trip number between production zone *'i'* and attraction zone *'j'*; P_{ij} is trip production in zone *'i'*; A_j is trip attraction in zone *'j'*; F_{ij} is friction factor between zones *'i'* and *'j'*.

Many sources consider distance is not the only variable that plays an important role in transport. The combined function of time, distance and cost (usually called generalized cost), which is normally called a deterrence or friction function, is a significant variable (Tamin & Suyuti, 2007). Other sources stated that generalized cost was a combination between transport cost and the value of time (Mahmudah et al., 2011). The function of the friction factor takes the following form, as shown in Equations 2, 3, 4:

$$f(C_{id}) = C_{id}^{-\beta} \text{ (power function)} \tag{2}$$

$$f(C_{id}) = e^{-\beta C id} \text{ (negative exponential function)} \tag{3}$$

$$f(C_{id}) = C_{id}^{-\beta} \, x \, e^{-\beta C id} \text{ (tanner function)} \tag{4}$$

If the value of C_{id}, O_i, and D_d is known, then the other unknown parameters of DCGR are α and β. The assessment process of valuing α and β is known as the calibration model.

To find the constants, α and β in the calibration model, when we know the value of T_{id} and C_{id}, we could use a linear regression as substitute, to calculate a value such as $B = -\beta$ and $A = \log_e(A_i . B_d . O_i D_d)$ (Tamin, 2008), the function is shown in Equation 5:

$$A = \overline{Y} - B\overline{X} \tag{5}$$

where $\overline{Y}$ and $\overline{X}$ is the average value of Y_i and X_i.

2.1.2. Calibration

The calibration technique consists of bi-proportional and tri-proportional models. Comparing those two models, the tri-proportional model is more accurate because it uses data aggregation, such as total freight ends *Oi* and *Dj* and a deterrence function to avoid an incomplete freight matrix. The iteration stops when the corrections are small enough or the constraint is met within a reasonable tolerance value that is equal to 1 or within the interval of $0.95 \leq V \geq 1.05$ (Tamin, 2008).

2.2. Interaction among Models

The input and output of each model are connected in this multi-layer framework. For example, the outputs from land use and an economy growth model are used as the inputs to a freight generation model, such as household characteristics. Regional EI model results are considered in the urban passenger freight generation model. The outcome of all regional, urban passenger and freight models are input to the time allocation model. Traffic flows, achieved from the traffic assignment model, are used as feedback to the network, and then freight distribution is updated iteratively to reach stable traffic assignments. The final results of the traffic module are the input of the other models, such as an emissions model. For example, from the transportation module, the road function and the volume of each type of vehicle are obtained, so the travel miles and the emissions unit of each type of vehicle can be used to get the total emissions. The accessibility and connectivity of land use can be obtained from the model as a measurement to evaluate different land use scenarios and also to provide feedback to the land use model, as a parameter for residents and employees location choice.

3. RESULTS AND DISCUSSION

The calibration of freight distribution from two comparative models can be seen in Tables 3 and 4. These tables show comparison of the Gravity model using calibrated parameters for estimation with a linear regression method. Notation *O1* and *D1* until *O8* and *D8* means that Origin or Destination from Zone 1 to Zone 8 for each origin and destination, respectively.

Table 3 Comparison of distribution models furness and maximum entropy (1)

Iteration	**1**		**2**		**3**	
Model	Furness	Max-Entr	Furness	Max-Entr	Furness	Max-Entr
O1	0.79	1.01	1.00	1.70	0.99	1.46
O2	0.87	1.04	0.98	0.42	1.02	0.51
O3	0.74	1.73	1.00	4.78	0.99	6.07
O4	0.82	0.97	0.99	2.02	1.00	1.60
O5	0.82	0.89	0.99	0.73	1.00	0.55
O6	0.79	1.01	0.99	1.01	0.99	1.02
O7	0.81	1.04	1.01	0.88	0.99	0.93
O8	0.83	0.89	1.01	0.94	0.98	0.85
D1	0.82	0.67	1.00	1.091	1.00	1.00
D2	0.82	0.96	1.02	1.001	0.98	1.00
D3	0.82	1.54	1.00	1.122	1.00	1.00
D4	0.81	0.50	1.01	0.272	1.00	1.00
D5	0.82	1.47	1.01	1.389	1.00	1.00
D6	0.81	2.19	1.01	6.840	1.00	1.00
D7	0.84	0.95	0.98	1.151	1.00	1.00
D8	0.84	1.05	0.98	0.546	1.01	1.00

And also the comparison of the distribution model within an interval of 0.95 ≤ v ≥ 1.05, shows that iteration in the Furness model finishes in the 4th iteration, while Maximum-Entropy finishes in the 6th iteration. Table 4 shows that iteration of the Furness model converges in 4^{th} iteration, since there was no change of value in the next iteration.

Table 4 Comparison of distribution model furness and maximum entropy (2)

Iteration	**4**		**5**		**6**	
Model	Furness	Max-Entr	Furness	Max-Entr	Furness	Max-Entr
O1	1.00	1.00	0.99	1.03	1.00	1.00
O2	0.98	1.00	1.02	0.90	0.98	1.00
O3	1.00	1.00	1.00	1.08	1.00	1.00
O4	1.00	1.00	1.00	0.99	1.00	1.00
O5	1.00	1.00	1.00	0.95	1.00	1.00
O6	1.00	1.00	1.00	1.07	1.00	1.00
O7	1.01	1.00	0.99	0.99	1.00	1.00
O8	1.02	1.00	0.98	1.02	1.02	1.00
D1	1.00	1.04	1.00	1.00	1.00	1.00
D2	1.02	0.94	0.98	1.00	1.02	1.00
D3	1.00	0.93	1.00	1.00	1.00	1.00
D4	1.00	0.55	1.00	1.00	1.00	1.00
D5	1.00	0.75	1.00	1.00	1.00	1.00
D6	1.00	1.10	1.00	1.00	1.00	1.00
D7	1.00	1.07	1.00	1.00	1.00	1.00
D8	0.98	1.28	1.01	1.00	0.98	1.00

Table 5 The estimated parameters of the gravity model

Estimation method	**Deterrence Function**					
	Negative Exponential		Power		Tanner	
	β	Iterations	β	Iterations	β	Iterations
Linear reg.	**0.00155**	6	**0.0117**	6	**0.0012**	6
Furness		4		4		4

Table 6 GOF statistical test

GOF statistics	**Deterrence Function**		
	Neg. Exponential	Power	Tanner
RMSE	110.1835938	0.076759	5.513282
R^2	0.4098	0.4097	0.4097

It can be seen from Table 5, which uses the negative exponential, power and tanner functions, that all interations resulted in positive values of β. This result means that any incremental increase in travel time (cost) between each corresponding zone decreased the number of flows between them. This condition follows what in reality is the higher the travel cost; the lower will be the number of flows between zones. While in Table 6 the data show the Goodness of Fit (GOF) statistical test of the estimated matrices compared to the observed matrices. This will be explained in greater detail, since in Table 6, according to the highest RMSE and R^2, the best friction factor closest to reality was the negative exponential comparing all three functions.

Using the Furness and Maximum Entropy models, the results show that the Furness model finished in the 4th iteration, rather than the maximum-entropy model which finished in the 6th iteration. However, logically speaking the Furness model is deficient in omitting the impedance factor, since the behavior of movement is concerning impedance (cost). While the positive value of β means that any increment in travel time between each corresponding zones decreased the number of flows.

However, using the Furness method required additional iterations for convergence, which is very much dependent on the starting value of the calibrated parameter. In this situation, the starting value of all cases was set to 1 (one). The number of iterations for convergence was reduced, when the initial value of the calibrated parameters was closer to the expected value.

The use of the negative exponential function gives a better fit, compared to the tanner and power functions, even though the value of R^2 resulting from the calibration process was still not good enough (maximum 0.4098). This could be happening because there are a lot of zero values in the existing (observed) freight OD matrix (Tamin & Suyuti, 2007).

4. CONCLUSION

This study revealed the disadvantages in current freight transport models and a proposed regional multimodal transportation model, based on adopting the traditional four-step model. The model introduces a time allocation step, suggests better approaches in steps, such as freight distribution, and improves the connections among each model. This model framework incorporates land use and transportation systems, and is capable of evaluating interactions between land use and transportation planning.

It was found that a regional origin-destination freight distribution model and the negative exponential function of the friction factor gave the best estimation in the origin-destination freight matrices. Even the maximum-entropy model is more time consuming than the Furness model, since it uses more complicated algebra and other procedures. In conclusion, the purpose of this research is aimed at comparing the effectiveness of different freight transport models to connect inter-island freight transport in Indonesia, using a case study modeling intra-city freight flow in the archipelagic region of northern Maluku.

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