Policy Evaluation of Multimodal Transportation Network: The Case of Inter-island Freight Transportation in Indonesia

Ade SJAFRUDDIN \textsuperscript{a}, Harun Al-Rasyid S. LUBIS \textsuperscript{b}, Russ Bona FRAZILA \textsuperscript{c}, Dimas B. DHARMOWIJOYO \textsuperscript{d}

\textit{Transportation Research Group, Institut Teknologi Bandung (ITB), Jl. Ganesha 10 Bandung – 40132, Indonesia}

\textsuperscript{a} E-mail: ades@trans.si.itb.ac.id
\textsuperscript{b} E-mail: halubis@si.itb.ac.id
\textsuperscript{c} E-mail: frazila@si.itb.ac.id
\textsuperscript{d} E-mail: dimas@trans.si.itb.ac.id

Abstract: This paper outlines the development of an analytical model of multimodal, multi-commodity freight transportation in Indonesia. The model is used to evaluate strategic planning of inter-island freight transportation. The demand for inter-island freight transportation is estimated using econometric demand models which account for the socio-economic characteristics of the regions and commodity types. The supply side is concerned with modeling the inter-island transportation network, including links, such as the land access network, and transfer points which are connected by the links, and a generalized cost function. System optimization is obtained by identifying the combination of links and transfers that minimize the total generalized transport cost. The model is applied to the evaluation of the impacts of several policy scenarios which contribute to the improvement of the inter-island freight transportation network. The model has shown its capability of estimating system costs of transportation network that can be utilized to assess the policy implications.

Keywords: Freight transportation, Multimodal, System optimum, Regional network

1. INTRODUCTION

Sea freight transportation network plays a vital role in Indonesian economy since the country covers over 5 million square kilometers area with over 17,000 islands. Since 1980s the annual growth of freight transportation ranged 10-20\% by railways, 5-10\% by air, and 10-15\% by sea. Connectivity and efficiency of the existing inter-island transportation network, however, has faced serious problems. This has led to the high cost of transportation that in turn affects the competitiveness of the economy.

With respect to inter-island freight transportation network, the situation is more problematic as transport of commodities normally involves two or more different modes. At the transfer points, problems related to loading and unloading of commodities, scheduling, warehousing, different destinations, and so forth are of significant interest.

This research aimed to develop a methodological approach to evaluate optimum freight transportation network in terms of a generalized transport cost. A model is formulated in such a way that the network and the demand are interrelated to each other. This is so that the model will be capable of evaluating transport policy changes. A multimodal system and the cost model are developed based on the respective characteristics of each mode. STAN (Strategic Transportation ANalysis, INRO Consultants, 1997) is the software used in this research, since it can be used to model multimodal transportation network comprehensively and carry out a strategic planning model.
In more detail, the research objectives are stated as follows:

- to develop an inter-island freight transportation demand model by commodity types;
- to develop a generalized cost model for inter-modal freight transportation;
- to develop a method to analyze the optimality of the freight transportation network based on costs;
- to conduct policy analysis of alternatives for strategic development of freight transportation network in Indonesia.

Previous researches on freight transportation in Indonesia have been conducted. Sjafruddin et al. (1997, 1999) developed regional freight transportation demand models for various transportation modes. These models estimated the demand for intercity freight transportation with region’s social economic factors and transport systems attributes. Factors identified as significant in generating freight transport demand include population, GRDP, GRDP per capita, proportion of industrial sector product, production surplus, and deficit. The calibration of these models, however, was based upon the quantities of total commodities without commodity classification and this limits its use for a policy evaluation. Prasetyo (1999) developed an approach to analyze multi-mode multi-commodity freight transportation network for Java Island with an emphasis on modeling of transfer points. He specified an appropriate way to represent a multimodal network and to model a transfer point in the network model. Prasetyo applied the methodology in evaluating some land transportation network development in the Java Island. His findings, however, were limited as the model only represents total commodity flow. Hermawan (1999) developed mode choice models of intercity freight transportation on Java Island. The model choice model was calibrated for two modes, namely truck and train, based on a binary logit model using stated preference data. The resulting models were regarded as reasonable enough to be applied for evaluating policy scenarios, but the methodology did not model the transfer point explicitly. Lubis et al. (2002, 2003) examined the optimization of national freight transportation network based on a multimode multi-commodity approach and utilized the STAN software. Eastern Indonesia was studied with respect to its transportation development plans including port system improvement and a new regional railway network on Kalimantan Island. The demand was estimated based on the available inter district O-D data and expanded for the future using a growth factor. This research made conclusions about the preferable development scenario based on network performances and benefit-cost analysis. Frazila (2005) developed regional freight transportation network model for Indonesia utilizing a genetic algorithm approach. He derived detailed cost parameters for the link cost functions and transfer time estimation which is assumed consisting of loading-unloading time and affected by capacity at transfer point. Furthermore, a genetic algorithm procedure was developed to model the optimal flows in the network. Crainic et al. (1990) reported findings related to the application of STAN for strategic transportation analysis in Brazil. This research developed a methodology to establish the cost function and the assignment procedure for the regional commodity flow and shown the capability of the model to evaluate strategic planning of multimodal, multi-commodity freight transportation network.

2. RESEARCH OUTLINE

The analysis covers following aspects:

- the pattern of the demand for regional freight transportation in Indonesia;
• the existing system of freight transportation network consisting of inland links, transfer points, inter-island links;
• the development of the system to cope with the growth of demand for inter-island freight transportation.

Figure 1 describes the general outline of the steps and aspects of the research.

![Figure 1. Research outline](image)

3. MODELING APPROACH

3.1 Demand Model

An econometric model utilizing variables describing characteristics of the freight and/or regional conditions is employed. The resulting models are therefore sensitive to social-economic changes that are represented by the variables.

The total amount of commodity movement between a pair of cities is assumed to be a function of certain social economic characteristics of these cities. The general form of the demand model is specified as follows:

Model 1: \[ T_{ij} = \alpha(X_i X_j)^\beta (Y_i Y_j)^\gamma \]  
Model 2: \[ T_{ij} = \alpha(X_i X_j)^\beta \]  
Model 3: \[ T_{ij} = \alpha(Y_i Y_j)^\gamma \]
where:
\[ T_{ijk} \]: volume of commodity \( k \) produced in zone \( i \) and transported to zone \( j \), in tons/year,
\[ X_i, X_j \]: number of population of zone \( i \) and zone \( j \), in 1,000 people,
\[ Y_i, Y_j \]: GRDP (Gross Regional Domestic Product), total or industrial sector, of zone \( i \) and zone \( j \), in \( 10^9 \) Rupiah, and
\[ \alpha, \beta, \gamma \]: model parameters.

Considering that the industrial sector induces a very significant impact to the flow of commodities from and to a region, GRDP of industrial sector was also utilized as an alternative variable in spite of total GRDP. The model, which is an aggregate model and utilizes aggregated data, is considered useful as a tool to evaluate impacts of policy changes to the existing system rather than to generate absolute estimates of freight tonnage.

3.2 Network Model

The basic components of the modeling framework and related data requirement are illustrated in Figure 2. The network represents the infrastructure and services that form the supply side, mode represents how activities are carried out, node and link represent the spatial structure of the transport system, and transfer shows operational characteristics of interchange between modes. The demand side is identified as products or groups of products, production and consumption rate per unit area of analysis, and the demand for respective commodities transported from one place to another.

![Figure 2. Main model components, STAN (Strategic Transportation ANalysis)](Source: INRO Consultants, 1997)
The simulated network consists of a number of elements. Details of the elements are shown in Figure 3. The main elements consist of mode, node and link, vehicle, transfer, and functions that follow a particular structure and are defined hierarchically. Every element is specified by certain attributes that determine how they interact to each other.

A simple illustration of a network is shown in Figure 4. In this figure two modes are indicated, namely road and rail. City A to B is served by all modes, whilst A to C and B to C are served by road only. In the simplified representation all cities are connected each other by direct links and modes are allocated as attributes of links.

The transfer deserves special attention. Transfers are defined as a separate process of movement between a node and mode. Figure 5 shows a mode interchange and its development at the node.

Figure 3. Network elements in STAN, hierarchy and attributes

3.3 Cost Function and Assignment Procedure

The network optimization model that is used to simulate network flows in STAN is a nonlinear multiproduct multimode assignment formulation that minimizes the total generalized system cost of shipping the products considered, from origins to destinations, via the permitted modes, while satisfying the usual flow conservation and non-negativity
constraints. Capacity constraints and congestion phenomena on various transportation modes are specifically considered by using volume/delay and penalty functions.

The total generalized system cost to be minimized is:

\[ \text{total generalized system cost} = \text{total cost on links} + \text{total cost on transfers} \]  

(4)

where the total costs of a product on a link (or transfer) are:

\[ \text{total link costs} = \text{link total unit product cost} \times \text{product volume} \]  

(5)

\[ \text{total transfer costs} = \text{transfer total unit product cost} \times \text{product volume} \]  

(6)
The link and transfer unit costs for a given product are a user-defined combination of up to three functions:

\[ s_{pa}(v) = a \times \text{link "operating" cost (v)} + b \times \text{link "delay" cost (v)} + c \times \text{link "other" cost (v)} \]  

(1st cost function)  
(2nd cost function)  
(3rd cost function)  

(7)

where other costs may be energy consumption, potential hazards, environmental impacts, or others, and \( v \) denotes the flow of all products on the multimodal network.

The total cost of the flow on arc \( a \), \( a \in A \) (a set of arcs), for the product \( p \), \( p \in P \) (a set of all products considered), is the product \( s_{pa}(v) v^{p}_{a} \), while the total cost of the flow on transfer \( t \), \( t \in T \) (a set of transfers), is \( s_{pt}(v) v^{p}_{t} \). We then have:

\[ s_{a}(v) = \sum_{p \in P} s_{pa}^{p}(v) v^{p}_{a} \]  

(8)

\[ s_{t}(v) = \sum_{p \in P} s_{pt}^{p}(v) v^{p}_{t} \]  

(9)

The link (transfer) function set indicates the functions associated with each product on each link (transfer), where:

- \( s_{a}(v) \): total cost of the flow on the link
- \( s_{t}(v) \): total cost of the flow on the transfer point
- \( s_{pa}^{p}(v) \): unit cost of product \( p \) on the link
- \( s_{pt}^{p}(v) \): unit cost of product \( p \) on the transfer point
- \( v^{p}_{a} \), \( v^{p}_{t} \): the flow of product \( p \) on the link, or on the transfer point

The total generalized system cost, that is the total cost of the flows of all products over the multi-modal network, is the function \( F \):

\[ F = \sum_{p \in P} \left( \sum_{a \in A} s_{pa}^{p}(v) v^{p}_{a} \right) + \sum_{t \in T} s_{pt}^{p}(v) v^{p}_{t} \]  

(10)

The multiproduct, multimode assignment model is carried out based on minimizing total general system cost as defined in equation (10).

4. DATA AND MODEL PARAMETERS

4.1 Data

Data on inter-island commodity flows through ports were obtained from a domestic sea transportation study (JICA, 2003). The JICA study specified the commodities into 13 categories (Petroleum, CPO, Other Liquid, Coal, Other Mines, Rice, Agri Grains, Fertilizer, Cement, Other Grains, Fresh Products, Forestry Products, and Others (General Cargo) with four packaging types, namely container, break bulk, dry bulk, and liquid bulk. The JICA study estimates the annual origin-destination of commodity flows by ports.
Data on existing transportation networks were obtained from Ministry of Communication and various transport operators. The data includes network condition, services attributes, and fares. The data was used to derive parameters for the cost functions and variables of the link and transfer services of the networks under consideration.

Indications of potential policies for transportation network development were obtained from varying previous studies and plans. These include the development plans for the port system, highways, toll roads, and railways in the areas under study.

4.2 Resulting Demand Model

The demand models for this research were developed for 5 commodity types, namely CPO+Other Liquid, Rice+Agri Grains, Other Grains+Fresh Product, Forestry Product, and Others (General Cargo). These commodities are common and associated with general consumption by communities in these regions, and can be accommodated by most general ports in Indonesia. Other commodities such as petroleum, coal, other mines, fertilizer, and cement were not modeled as these are related to specific areas or industries and are normally handled by special ports. O-D tables were built based on this data, and disaggregated across 42 zones covering entire area of Indonesia. Each zone represents a port hinterland covering the area of one or more districts. The resulting O-D table for each commodity is then used to calibrate the freight transportation demand model.

A number of combinations of explanatory variables are tested in the demand model calibration. Based on some statistical tests and reasonableness of parameters, Table 1 presents the best demand models derived by commodity type. These demand models are used to estimate the inter-island freight transportation flows in the baseline year 2006.

<table>
<thead>
<tr>
<th>No</th>
<th>Commodity</th>
<th>Model</th>
<th>( R^2 )</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CPO + Other Liquid</td>
<td>( T_{ij} = 0.01 \times 10^3 (X_i \times X_j)^{0.51} (Y_i \times Y_j)^{0.69} )</td>
<td>0.66</td>
<td>Population, GRDP Industry</td>
</tr>
<tr>
<td>2</td>
<td>Rice + Agri Grains</td>
<td>( T_{ij} = 0.10 \times 10^3 (X_i \times X_j)^{0.45} (Y_i \times Y_j)^{0.74} )</td>
<td>0.46</td>
<td>Population, GRDP Industry</td>
</tr>
<tr>
<td>3</td>
<td>Other Grains + Fresh Product</td>
<td>( T_{ij} = 2.40 \times 10^3 (X_i \times X_j)^{0.15} (Y_i \times Y_j)^{0.65} )</td>
<td>0.64</td>
<td>Population, GRDP Industry</td>
</tr>
<tr>
<td>4</td>
<td>Forestry Product</td>
<td>( T_{ij} = 0.123 (X_i \times X_j)^{0.45} (Y_i \times Y_j)^{0.30} )</td>
<td>0.58</td>
<td>Population, GRDP Industry</td>
</tr>
<tr>
<td>5</td>
<td>Others (General Cargo)</td>
<td>( T_{ij} = 1.106 (X_i \times X_j)^{0.28} (Y_i \times Y_j)^{0.38} )</td>
<td>0.60</td>
<td>Population, GRDP Industry</td>
</tr>
</tbody>
</table>

*Note: X denotes number of population (in 1,000), Y denotes GRDP (in 10^9 Rp)*

4.3 Cost Functions

Unit generalized cost is expressed as a function unit link cost, unit transfer cost, and the travel time value of commodity, and specified as follows:

\[
C_p = \alpha_{lp} + \alpha_{tp} + \beta_p (t_1 + t_t)
\]

where:

- \( C_p \) = unit generalized cost (Rp/ton)
- \( \alpha_{lp} \) = link unit cost (Rp/ton)

\( (11) \)
\[ c_{ap} = \alpha_p l_a + \beta_p t_a \]  

where:  
- \( c_{ap} \): generalized cost (Rp/ton) at link \( a \)  
- \( \alpha_p \): fare (Rp/ton/km) at a transfer link  
- \( \beta_p \): value of time (Rp/ton/hr)  
- \( t_a \): travel time at link (hr)  
- \( l_a \): length of link \( a \) (km), \( l_a = 1 \) for transfer link

Based on the data obtained from transport operators, Frazila (2005) derived the following cost parameters for the link cost function (which were used in this study):

1. Link parameters of roads: \( \alpha_p = 0 \), \( \beta_p = \text{Rp 7/hr/ton} \);  
2. Link parameters of toll roads: \( \alpha_p = \text{Rp 200/ton/km} \), \( \beta_p = \text{Rp 8/hr/ton} \);  
3. Link parameters of sea: \( \alpha_p = \text{Rp 43.9/ton/km} \),  
   \[ \beta_p = \begin{cases}  
   \text{Rp 5/hr/ton for container cargo,} \\
   \text{Rp 5/hr/ton for dry bulk cargo,} \\
   \text{Rp 6/hr/ton for break bulk / general cargo,} \\
   \text{Rp 5 hr/ton for liquid bulk;} 
   \end{cases} \]

Transfers identified in this study are the following:
- Transfer between land transportation and sea transportation; and  
- Transfer between ferry and sea transportation.

Transfer time is assumed to consist of loading-unloading time and affected by the capacity at the transfer point which in turn depends on the number of berths and delays during the process. Following equation is used to estimate transfer time at a port (Frazila, 2005):

\[ t = t_o + \frac{tbm}{1 - \frac{vol}{cd \cdot n}} \]  

where:  
- \( t \): time at port  
- \( t_o \): delay at port for inspection, administration, berthing, etc which is assumed 6 – 48 hr  
- \( t_{bm} \): loading-unloading time (hr)  
- \( vol \): total loading-unloading flow (ton/hr)
capacity of loading-unloading (ton/hr/berth)

number of berth (unit)

The value of time at transfer points is assumed to be equal to link value of time for all packaging. Cost parameters for transfer points at ports are obtained based on the available data as presented in Table 2.

<table>
<thead>
<tr>
<th>Description</th>
<th>Fare / $\alpha_p$ (Rp./ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unloading at major ports</td>
<td>2,023</td>
</tr>
<tr>
<td>Loading at major ports</td>
<td>1,025</td>
</tr>
<tr>
<td>Unloading at other ports</td>
<td>2,492</td>
</tr>
<tr>
<td>Loading at other ports</td>
<td>862.5</td>
</tr>
</tbody>
</table>

5.1 Simulated Policy Scenarios

Policy scenarios of network development in Java Island consist of:

A1. Existing condition, where the condition of the road network is much better than that of other modes. The existing railway network connects most main cities and regions in Java, but most links are single tracks and the level of service is considerably low.

A2. Trans Java Toll Roads Development (Figure 6) that fully connects all provincial cities in Java and improves road network capacity especially in the northern part of Java. This includes the existing toll roads plus 6 new links (Jakarta-Semarang, Semarang-Demak, Demak-Solo, Solo-Surabaya, Surabaya-Malang, Gempol-Banyuwangi).

A3. Java Railway Development, a capacity expansion by building double tracks railways in Java including access links to ports, especially in the busy, northern part and several links in the southern area where the majority of cities and districts are connected by railways, and improvement of services is done to meet the demand.

Policy scenarios of network development in Sumatera Island consist of:

B1. Existing condition, where the road network is used much more by traffic. The existing railways in Sumatera are situated at three regions where railway networks are unconnected to each other and the services are very limited.

B2. Improvement of Trans Sumatera Highway Network, especially in the west, east, and middle routes.

Figure 6. Trans Java toll roads development
B3. Development of a fully-connected Trans Sumatera Railways (Figure 7), consisting of the improvement and construction of new links, to fully connect all provinces in Sumatera and the improvement of services so as to meet the demand. The existing railways in Sumatera are situated in 3 areas and are unconnected to each other; and this development adds 13 new links of railways.

Policy scenarios for the inter-island network development consist of:
C1. Existing condition, where the land transportation in the existing condition and the port system does not have a hierarchy of a hub-spoke system.
C2. Implementation of Hub-Spoke Ports with 15 hubs (Figure 8), namely Medan, Batam, Palembang, Padang, Bengkulu, Jakarta, Surabaya, Cilacap, Pontianak, Banjarmasin, Balikpapan, Bitung, Makassar, Ambon, and Sorong. This is to represent the policy to assign a number of ports as hub that services longer distance inter-island movement and every hub connects to several spokes as feeder.
C3. Implementation of Hub-Spoke Ports with 9 hubs (part of Figure 8), namely Medan, Batam, Palembang, Jakarta, Surabaya, Banjarmasin, Makassar, Ambon, and Sorong.
C5. Development of Fully Connected Trans Sumatera Railways as in B3.

Figure 7. Trans Sumatera railways development

5.2 Simulation Results
The simulation was carried out to determine the optimum condition of the modeled policy scenario based on the total (link plus transfer) multimodal transportation cost.

Figure 9 shows that the development of double tracks in the Java Railway Network significantly reduces the system cost and this is much better than the impact of the development of the Trans Java Toll Roads. This is mainly brought about by greater cost efficiency of the railways. As the double-track railways become available, most bottlenecks of inland transportation, as access to ports in Java, will be relieved and a substantial portion of existing road freight traffic will be diverted to railways. The railway network is also covering most areas of production centers in Java and the railway development will certainly provide better direct access to inter-island ports. And, the benefit of using the railway will increase as travel distance becomes longer. The Trans Java Toll Roads development will also improve the inland transportation network, but its impact will not be as substantial as the railways development since the toll roads are less cost effective than railways and mainly improve capacity in the northern area.

As seen in Figure 10 the Trans Sumatera Railway development will substantially reduce the total system cost of inland freight transportation. This is mainly due to the high cost efficiency of railways and the policy will divert a substantial portion of inter-island road freight traffic to railways especially for longer distance traffic. The system improvement is also obtained from better intermodal transfers as the simulated railway network provides direct access to inter-island ports from main production centers in Sumatera.

The performance of inter-island network will be improved by the implementation of hub ports together with designated spokes as feeder to the hubs. The implementation of the 9-hub system, as seen in Figure 11, results in lower system costs than the 15-hub system which suggests that more hubs do not necessarily mean more efficient inter-island port system.
Figure 9. Intra-Java commodity transportation, optimum system cost by policy scenario

Figure 10. Intra-Sumatera commodity transportation, optimum system cost by policy scenario

Figure 11. Inter-island Indonesia commodity transportation, optimum system cost by policy scenario
The implementation of hub-spoke ports represents an improvement to the system hierarchy of inter-island port system and this increases the efficiency of freight transportation system through better inter-modal or intra-modal transfer at ports. This policy also reduces the number of inefficient direct links between inter-island ports and results in better economies of scale of services in both main and feeder links. The improvement of the inland transportation network simulated here, both the Trans Java Toll Roads and the Trans Sumatera Railways Development, will also bring about some benefit to the inter-island transportation as these provide better access to the ports.

6. CONCLUSIONS

Several remarks could be drawn from this research as follows:

- Demand models by commodity type (CPO+Other Liquid, Rice+Agri Grains, Other Grains+Fresh Product, Forestry Product, and Others/General Cargo) for inter island freight transportation in Indonesia have been developed and can be utilized to estimate the volume of commodity in a certain time.
- The development of the railway network will substantially reduce the inland transportation cost and also induce some benefit to the inter-island transportation network. The potential system improvement by railways development is apparently much higher than by road development.
- The implementation of hub-spoke ports, representing an improvement to the system hierarchy of inter-island port system, increases the efficiency of freight transfer at ports and reduces the number of inefficient direct links between inter island ports which therefore improves the economies of scale of services in both main and feeder links.
- The simulated policies in this research, however, cannot be interpreted as final for the purpose of actual implementation. Further analysis of economic and financial feasibility of the plan still needs to be conducted.

ACKNOWLEDGEMENTS

This research was supported by the Competitive Research Grant Program (Hibah Bersaing) Batch XIV 2007 of the Directorate of Research and Community Services, Directorate General of Higher Education, Ministry of National Education.

REFERENCES


