MULTIMODAL FREIGHT ASSIGNMENT MODEL CONSIDERING TERMINAL PERFORMANCE*

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1. Introduction

The effect of terminals in the travel cost of freight in equilibrium network analysis is significant, particularly in short to medium distance freight movements. Freight movement using several modes is necessary for continuous and efficient network system in an archipelagic country like Indonesia, where multimodal terminals have played an important role in the movement of freight. Hence, for the purpose of strategic planning of freight networks, a predictive network model that sufficiently considers the effect of terminals is required. Furthermore, in cases where freight and passenger trips are less separated than other modes in using the infrastructure especially on the road network, the effect of freight movement on passenger trips, or vice versa, may be considered. It is, therefore, worthy to include passenger trips in the predictive freight network model simultaneously.

Although many predictive freight network models have been developed using various approaches with specific limitations[1) – 6)], the available data for freight transportation in many cases, such as in Indonesia, are insufficient for certain levels of model application[5)]. The available data in Indonesia from the national origin-destination and transport facility surveys are more viable for an aggregate-based model [4)].

2. Research Framework

(1) General

This paper discusses the model development of an aggregate assignment problem for freight transportation, which takes into account the effect of terminals and passenger trips in the strategic level of planning. The assignment problem is solved through network modeling, in which freight demand, trip generation and distribution are assumed exogenous. Modal split and route choice are carried out simultaneously (see Abdulaal and LeBlanc[7)]) with the assumption of unchanged trip cost rate due to changes in mode share.

Freight and passengers are treated as multi-class users[8)] with different cost functions on the links (link-ways and terminal links). Because of the characteristics of modes in transporting goods and passengers, the model can be simplified by assuming that the cost function of passengers are mutually-exclusive with the cost function of freight, except for the road mode.

(2) Network and Terminal Representation

Representation of the physical transport network is in the form of links and nodes. Basically, nodes are only functioned for link identifications and no penalties are applied on them. There are several types of links, such as centroid connectors, which connects the origin/destination point (centroid) to the network; link ways which differed among modes, and terminal links. To determine the explicit effect of terminals, it is necessary to add more arcs representing the processes in the terminal. For a three-mode multimodal terminal, there should be loading-unloading activities, train spotting and switching, drayage, waiting for vehicles or storage including inspections, and other administrative processes (Figure 1). This is a more detailed transfer node/terminal modeling that is different from previous models[3) – 6)] and is close to the hypernetworks defined by Sheffi and Daganzo[9)].

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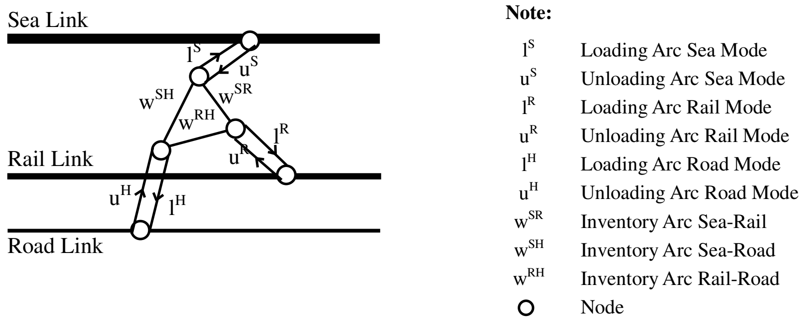

Figure 1: Arcs representing a multimodal terminal

Cost function for sea and rail links is represented by Equation (1). For the road links, the cost function is represented by Equation (2), which shows a more detailed delay function taken from the US-BPR with adjustments in initial travel time, capacity and conversion factor from tonnage to passenger car unit.

$$c_k^S = d_k \rho_k^S + \alpha \frac{d_k}{v^S} \tag{1}$$

$$c_k^H = d_k \rho_k^H + \alpha\, t_O \left\{ 1 + 2.62 \left[\frac{Fot + \left((PF \cdot f) \big/ (lp \cdot tc) \right)}{Cap} \right]^5 \right\} + \alpha \left(\frac{t_O}{4} \right) \cdot \frac{0.5}{lp} \tag{2}$$

where,

c_k^m : marginal freight rate on link k using mode m (m could be S for sea mode; R for rail mode or H for road mode)
d_k : length of link k
$\rho_k{}^m$: freight rate in link per length unit using mode m
α : average time value
v^m : average speed at link by mode m
t_0 : travel time at free flow speed
PF : average passenger car unit factor of trucks
Fot : other traffic (pcu)
f : flow (tones)
lp : length of planning time
tc : average truck capacity (tones/truck)
Cap : road capacity (pcu/hour)

The cost function for terminal links is composed of the handling cost and the time cost, differentiated into an unloading arc (Equation 3) or a loading arc (Equation 4), which are both based on the time function in the (M/M/1) queue system. The inventory arc is represented by all other costs and delays in the terminal related to drayage, inspections and inventory, among others. Since this arc represents the un-modeled processes in the terminal, the cost and delay on this arc are, therefore, fixed values.

$$c_u^m = \rho_u^m + \alpha \left(\frac{t_u}{1 - \frac{f}{N} \big/ \mu_u} \right) \tag{3}$$

$$c_l^m = \rho_l^m + \alpha \left[\left(\frac{t_w}{1 - f \big/ q \cdot cv} \right) + \left(\frac{t_l}{1 - \frac{f}{N} \big/ \mu_l} \right) \right] \tag{4}$$

where,

$c_{l/u}{}^m$: marginal freight rate on unloading or loading arc of mode m
$\rho_{l/u}{}^m$: unit handling cost using mode m

α : average time value
t_w : waiting time
$t_{l/u}$: loading/unloading time
q : vehicle's frequency
cv : average vehicle's capacity
$\mu_{l/u}$: loading/unloading capacity
f : flow (tones)
N : number of apron

(3) Solution Method

Based on the assumption that the marginal cost of freight transport using a particular mode is inelastic to the shared volume by mode, the objective function would only be to minimize the total generalized system cost and yield the inverted demand curve equation suggested by Ortuzar and Willumsen[10] for simultaneous modal split-trip assignment analysis. The objective function is then expressed as follows:

$$Minimize \quad C(f) = \sum_p \left[\sum_l c_l^p(f) f_l^p + \sum c_a^p(f) f_a^p \right] \tag{5}$$

$$subject\ to \quad \sum_k h_k = T_{od} \qquad k \in K^p{}_{od},\ \ o \in O,\ \ d \in D,\ \ h_k \geq 0 \tag{6}$$

where,
$C(f)$: total cost
$C^p{}_l(f)$: cost on link l by freight or passenger flow ($l \in L$, set of link, p is freight or passenger vehicles)
$C^p{}_a(f)$: cost on terminal arc a by freight or passenger flow ($a \in A$, set of terminal arcs)
$F^p{}_l$: flow of freight or passenger on link l
$F^p{}_a$: flow of freight or passenger on terminal arc a
h_k : flow on path k ($k \in K^p{}_{od}$, set of paths joining origin o and destination d for freight or passenger)
o : origin node ($o \in O$, set of origin centroids)
d : destination node ($d \in D$, set of destination centroids)

The solution algorithm is developed from Frank-Wolfe algorithm using Dijkstra's Method to find the least cost path. Successive average method is used to calculate the volume from the previous iteration (refer to Bell & Iida[11]) and the resulting difference between link costs in successive iteration is used for the iteration stopping criterion[12].

3. Preliminary Results

The model is tested using simple artificial network that connects a pair of zones composed of road, rail and sea links (Figure 2) with some scenarios on the rate pattern of modes.

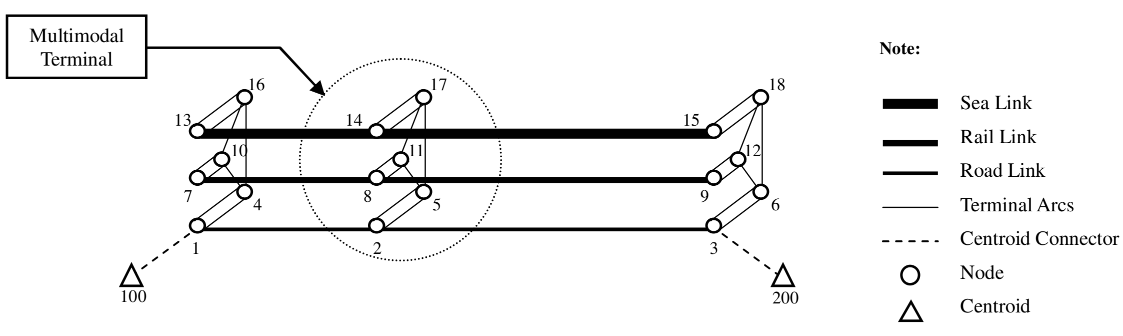

Figure 2: Simple network for preliminary model testing

Model results show that in the scenario with equal rate, freight trips are likely to be shared between road and rail transport. This may be attributable to the cost of waiting time for sea mode. In the scenario when the fare for the road mode is 20 times higher than the sea mode, the share of road mode is still the highest (86.6%) as the road mode is relatively faster with less terminal waiting time. On the other hand, passenger trips tend to avoid the road mode as the model only provides fixed delay on passenger terminals.

4. Expected Outputs

From the results of the simple network, the model can be applied with consistent results, even though the model still needs to be validated by real data. The major data to be used for the validation process are Indonesia's 2001 National OD data released by The Department of Communication, the database of transportation infrastructure from the Interurban Road Management System (IRMS) of the Department of Public Works and other data from transport facility surveys. Other necessary data can be derived from the available ones, such as time values, fares and capacities, while some can be assumed, such as time of inspection and inventory on terminals, among others. Validation can be performed by comparing values between the observed flow and the model result using the screen line method.

Further model application to determine the optimal location of regional freight terminals follows after the validation process. A bi-level programming approach is used (Figure 3) so that the model can be divided into two levels of problems. The behavior of trip makers, i.e. in this case the shippers and carriers, is described in the lower level problem, which involves choosing the freight terminal to use, the route to travel, including the behavior of the user in choosing the transport mode. The behavior of regulators and planners to optimize the system's objective function is described in the upper level problem, which determines the optimal location and size of freight terminals.

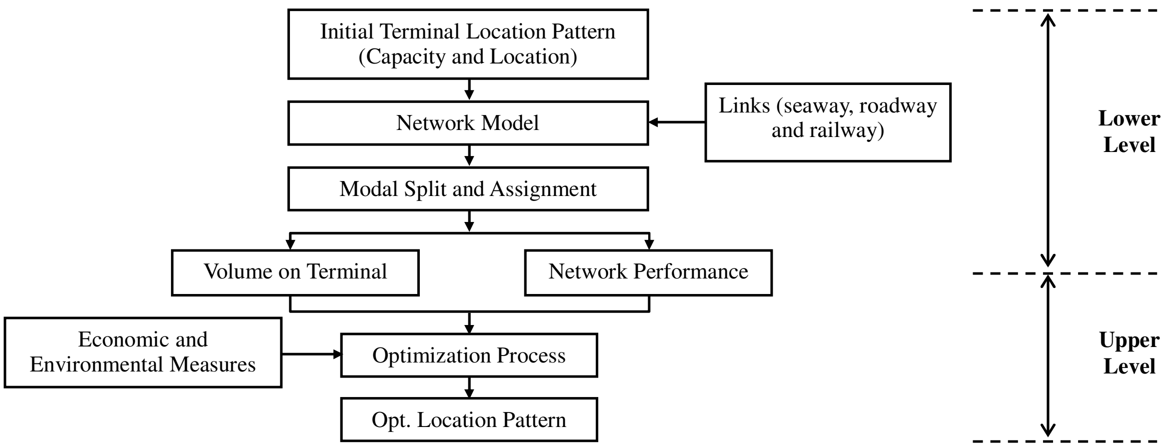

Figure 3: Bi-level programming for optimum freight terminal location analysis

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