OPTIMISING THE DESIGN OF FREIGHT TRANSPORT NETWORK IN JAVA ISLAND*

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1. Introduction

Basically, the purpose of transport network development planning is to identify and select actions that efficiently expand the network under the prevailing constraints (i.e. resources and environmental constraints). In the case where the alternatives are already available, the problem can be reduced to finding an optimal set of feasible actions. Thus, the problem can be transformed into a combinatorial optimisation problem.

This paper proposes a method to cope with such problems within the framework of bi-level programming problem, where a multimodal multi-user equilibrium traffic flow is described in the lower level problem and the combination of actions for capacity expansion of freight transport network is optimised using GA-based (GA: genetic algorithm) procedures in the upper level problem. This type of problem also involves a mathematical problem with equilibrium constraints. The advantage of GA-based approaches is that such approaches can facilitate the design of bi-level programming problems if applied as combinatorial optimisation techniques in the upper level problem as well as they can provide better solutions within reasonable computation times

The model is tested on the investment planning problem for freight transport network in Java Island, Indonesia, where network design in Java Island is desired to increase the utilisation of multimodal transport systems since emphasis has been given only on the road-mode that further worsens the transport system and results in severe social and environmental impacts. This paper, therefore, focuses on feasible actions for capacity expansion, which includes improving the existing capacity or building and establishing new roads, railways, sea links and freight terminals

2. Model Framework

(1) General

A bi-level programming approach is employed, where multimodal multi-user User Equilibrium (UE) assignment model is used in the lower level while the best combination of actions is determined in the upper level. A simplification is applied in modelling the network by omitting the influence of shipper-carrier behaviour and their interaction in the freight transport decision. This is due to the unavailabity of micro-level (i.e. multi commodity, shipper-carrier company level) data in Indonesia. The available data, which were primarily based on the national origin-destination and transport facility surveys, are more viable for an aggregate-based model[1].

(2) Lower Level Problem

Freight and passengers are treated as multi-class users, with modal split and route choice carried out simultaneously by converting the multimodal network into a unimodal abstract mode network. Therefore, the UE problem to be dealt with is a non-separable and asymmetric Jacobian matrix cost function among user types. This can be stated as a variational inequality problem as follows (see Dafermos[2]):

Find $x_a^{i*} \in \boldsymbol{\kappa}$ such that:

$$\sum_{i=1}^{p} c_a^i(\tilde{x}^*)\times(x_a^i - x_a^{i*}) \geq 0, \forall \tilde{x} \in \kappa, \forall a \in A \tag{1}$$

where x_a^{i*} is the User Equilibrium flows of link a for user type i, and $\tilde{x}$ is a p-dimensional column vector with the components $\{x_a^1,...,x_a^p\}$, and $\boldsymbol{\kappa}$ is defined as $\boldsymbol{\kappa} \equiv \{\tilde{x}|$ satisfying the non-negative path flows and conservation of flow }. $c_a^i(.)$ is the generalised cost on link a for user type i.

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A method widely used for solving this case of assignment problem is diagonalisation[3]. Essentially, this method keeps interaction effects constant while solving the assignment problem by a descent direction algorithm. When updating the flow of one user type in the next iteration, the other user type is considered constant. This is simultaneously undertaken until no significant changes on the flows are obtained. Based on Sheffi[4] and other diagonalisation results in Thomas[5], the basic condition for reaching convergence is that the link cost is only dominated by the flow on it. Even if the condition is violated, a satisfactory result can still be obtained as long as the link cost is Jacobian positive definite.

(3) Upper Level Problem

The combination of actions for network expansion is optimised on the basis of the ratio of reduced total generalised cost (in one year) and one-year investment and operational cost required by the combination of actions. This is the simplification of economic feasibility term benefit-cost ratio (BCR), which indicates the economic effectiveness of the action. The objective function for selecting the best combination of actions will be to maximise the BCR value of a combination of actions to be implemented, *z(y)*, as follows:

$$\underset{y \in Y}{maximise} \quad z(y) = \frac{G_o - \sum_{i \in F} \sum_{a \in A} x_a^{i*} c_a^i (x_a^{i*}, y_a)}{\sum_{a \in A} b_a y_a} \tag{2}$$

where:

G_o : total generalised cost of initial network without any action implemented

F : set of user types for freight transport

A : set of directed links

x_a^{i*} : link flows for each user type that are the solution for the user optimal equilibrium (UE) problem with a combination of action being implemented

$c_a^i(x_a^{i*}, y_a)$: generalised cost on link *a* for user type *i*

y_a : link existence (action implementation) indicator which has a binary value of 1 if the action related to link *a* is implemented, and 0 if it is otherwise

Y : set of combination of actions

b_a : investment cost of link, if action corresponding to it is being implemented

The total generalised cost of initial network without any action implemented can be formulated as follows:

$$G_o = \sum_{i \in F} \sum_{a \in A} x_{oa}^{i*} c_a^i (x_{oa}^{i*}, y_a) \tag{3}$$

where:

x^{i*}_{oa} : equilibrium link flow on link *a* in the initial network for user type *i*

The GA-based process is used to solve the upper level problem. In this process, the combination of alternative actions in the links, y_a, is randomly generated, and the chromosomes is created. The value of its objective function is calculated and its fitness is evaluated as well. A particular type of GA called Genetic Local Search (GLS) is applied, where the local search operator is incorporated after crossover and mutation. This operator investigates other two variations of individuals and searches the best among them. The variations (new individuals) are produced by determining a random location and swapping the neighbours.

3. Application

(1) Test Conditions

Java, the main island of Indonesia, is divided into 4 provinces that include the special province of Jakarta, the Capital city of Indonesia. The island covers only 7.0% of the total Indonesian land area, but is inhabited by around 58.8% of the total population in the year 2000. The current transport system in this area is composed of 13,802 kms of national-provincial roads (19% of Indonesian total), 461 kms of toll roads, and 3,852 kms of railway tracks with 14 commercial seaports and 24 non-commercial seaports.

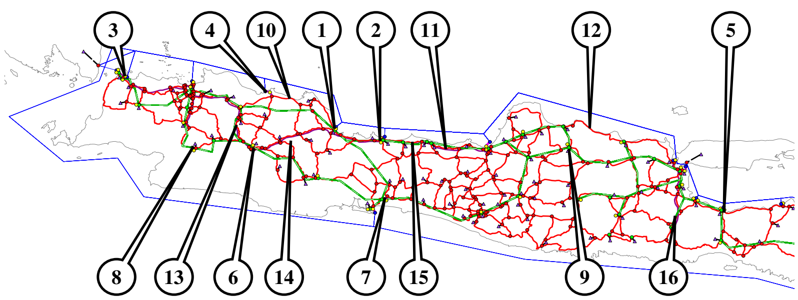
(2) Network and Actions

A number of link types are used, such as centroid connectors that connect the origin/destination point (centroid) to the network, link ways that vary among modes, and terminal links (also vary by type of activity inside the terminal). Each link type has different delay/cost characteristics, which are converted to a single type delay function using polynomial approximation proposed by Crainic et al.[6]. The transport network in Java Island is modelled into 86 zones consisting of 352 nodes and 2068 links comprising the national, provincial and toll roads, railways, 10 seaports and port-to-port connections. There are 16 alternatives of actions which include upgrading of existing infrastructure and development of new ones (see Figure 1) as culled from different infrastructure authorities.

(3) Results

The length of the chromosome used for genetic algorithm calculation is 16, which represents the number of proposed actions for capacity expansion. Based on suggestions by existing researches (e.g. Goldberg[7]), the suitable crossover rate is 0.6 and the mutation rate is 0.03 for small to medium cases. The number of individuals in each generation is set to 100 while the number of generations is set to 30. The number of generations is decided after performing a few trials on its adequate number.

The optimal solution only contains the action of number 7 (see Figure 1 for its location). Although it is the combination calculated to be the most efficient, it does not offer the maximum benefit (or the lowest total freight transport cost). The optimal solution improves the total freight network cost by 53.3%, while a solution with the action of number 1, 3, 5, 6, 9, 10, 12 and 13 improves 96.7% of the total network cost, which provides the best total network cost improvement. This is a reasonable result since the existing condition shows that heavily loaded links (freight flow > 100 thousand tons/day) occur around the main cities of Java Island (see Figure 2).



No.	Type of Action	Location
1	Sea Port Improvement	Cirebon
2	Sea Port Improvement	Tegal
3	New Sea Port	Ciwandan
4	New Sea Port	Karawang
5	New Sea Port	Probolinggo
6	Rail Terminal Improvement	Bandung
7	Rail Terminal Improvement	Maos
8	New Rail Terminal	Sukabumi
9	New Rail Terminal	Blora
10	Road Widening	Jakarta-Cirebon
11	Road Widening	Cirebon-Semarang
12	Road Widening	Semarang-Surabaya
13	New Express Way	Cikampek-Bandung
14	New Express Way	Bandung-Cirebon
15	New Express Way	Cirebon-Semarang
16	New Express Way	Gempol-Malang

Figure 1: Test network and alternative actions

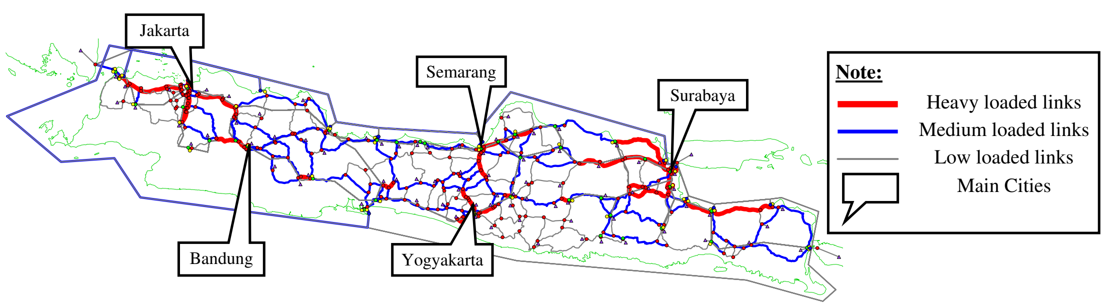


Figure 2: Present conditions on freight flow distribution

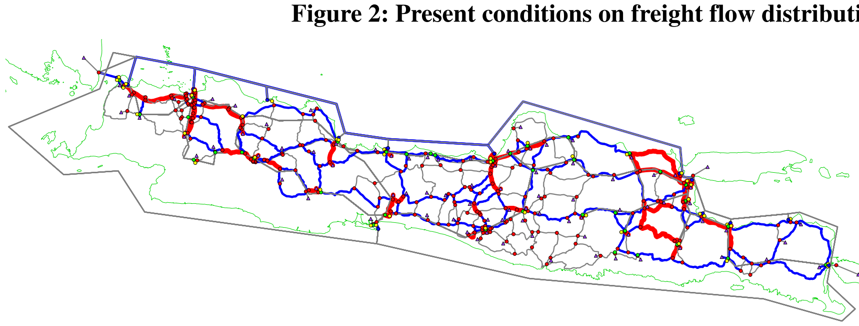


Figure 3: Freight flow distribution after implementing action no. 7

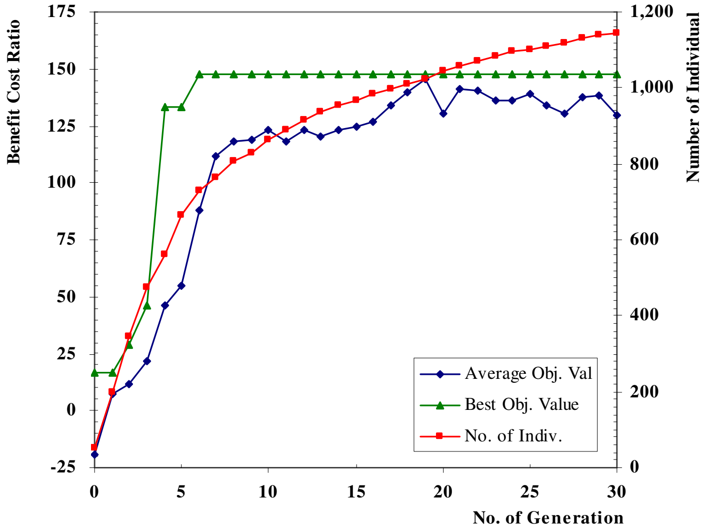


Figure 4: Performance of GLS procedure

Implementing action no. 7 would result in the shifting of some loads from road to railway and would reduce the number of heavy loaded road links as can be seen in Figure 3.

The performance of the model with GLS procedure is presented in Figure 4. It can be seen that the procedure has found the optimal solution within the 10th generation and nearly reached convergence after the 20th generation (difference between highest and average value is 1.9%). Therefore, it can be presumed that in this case, by using the GLS procedure, the required number of generation is 20. Subsequently, if using 20 generations, the number of evaluated individuals is 1142, which is 1.74% of the total number of possible combinations for 16 alternatives, i.e. $(2^{16} - 1) = 65,535$ combinations. Note that the ratio between sampled individuals and the possible combinations is very low. That can be considered as another advantage of using this approach.

4. Conclusions

This paper proposed a model that can be used as a tool for strategic level of planning, particularly in the development of freight network in Java Island. It presented a method for solving discrete network design problem, in this case selecting the best combination of actions based on their economic efficiency.

An optimisation model was developed, where a multimodal multi-user assignment technique is incorporated within the lower level problem and the optimal combination of actions for capacity expansion is determined using GA-based procedures in the upper level problem.

Results revealed that the model adequately found the best combination of actions among available alternatives with very low ratio of sampled individuals to the total possible combinations.

This paper provided only limited application, and therefore several different alternatives will be assessed for future research.

References

1) Lubis H. A., Sjafruddin A. and Frazila, R. B.: Port Planning with Multimodal Analysis, Report of Group Activities on Marine Transportation Engineering, JSPS Marine Transportation Program, Hiroshima University, Japan, pp. 238-260, 2002.
2) Dafermos S. C. :Traffic Equilibrium and Variational Inequality, Transportation Science 14, pp. 43-54, 1980.
3) Florian, M., Spiess, H.: The Convergence of Diagonalization Algorithms for Asymetric Network Equilibrium Problems, Transportation Research 16B, No. 6, pp. 477-483, 1982.
4) Sheffi, Y.: Urban Transportation Networks: Equillibrium Analysis with Mathematical Programming Methods, Prentice Hall, Englewood Cliffs, New Jersey, 1985.
5) Thomas R.: Traffic Assignment Techniques, Avebury Technical, England, 1991.
6) Crainic T. G., Florian M., Leal J. A : Model for The Strategic Planning of National Freight Transportation by Rail, Transportation Science 24(1), pp.1-24, 1990.
7) Goldberg, D. E.: Genetic Algorithms in Search, Optimisation, and Machine Learning, Addison-Wesley, 1989