Freight Transport Planning in Java Island: An Optimisation Model for Terminal Development and Network Expansion

Bona Frazila RUSS
Graduate School of Engineering
Hiroshima University, 1-4-1
Kagamiyama, Higashi-Hiroshima,
739-8527 Japan
email: frazila@hiroshima-u.ac.jp

Tadashi YAMADA
Graduate School of Engineering
Hiroshima University, 1-4-1
Kagamiyama, Higashi-Hiroshima,
739-8527 Japan
email: yamada@naoe.hiroshima-u.ac.jp

Jun CASTRO
Graduate School of Engineering
Hiroshima University, 1-4-1
Kagamiyama, Higashi-Hiroshima,
739-8527 Japan
email: junc@naoe.hiroshima-u.ac.jp

***Abstract* – This paper describes a model for determining an optimal freight transport network expansion plan that selects a set of feasible actions from a number of possible actions. The model is developed within the framework of bi-level programming problem, where a multimodal multi-user assignment technique is incorporated within the lower level problem and the combination of actions for capacity expansion is optimised using genetic algorithm-based procedures in the upper level problem. Some procedures on the basis of genetic algorithms are applied to investigate the performance of the model. Model application to the actual freight transport network in Java Island, Indonesia reveals that the model can adequately select the best combination of actions for optimal multimodal freight network expansion.**

I. INTRODUCTION

Capacity expansion of freight transport network infrastructure is inevitable in a developing country such as Indonesia, where the existing infrastructure has inadequate quantity and quality, and where growth rates for freight transport demand are extremely high.

Network capacity expansion planning can refer to investment planning, which in general may be transformed to a problem of selecting a set of feasible actions for capacity expansion from a number of possible actions to optimise some objective function. This problem can also be considered as a combinatorial optimisation problem.

This paper puts forward a method to cope with the problem 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 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 a capacity expansion problem for freight transport network in Java Island, Indonesia, where network design is desired to increase the utilisation of multimodal transport systems since emphasis has been given only on the road-mode that worsens the transport system and has resulted 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.

II. PROBLEM FORMULATION

We consider an abstract mode network $\eta(N,A)$, where N is the set of nodes and A is the set of links. Nodes represent cities or junctions where there are no associated delays or costs. Links, which are the conduits for flow between two nodes, represent not only physical infrastructures (i.e. roads, railways), but also activities that cause delay/cost to the flow (i.e. links representing the loading process in the terminal).

We allow $A=A_1\cup A_2\cup A_3$ as the set of directed links, with $A_1=\{a:a=1,2,...,n\}$ as the set of existing links that will not be modified, $A_2=\{a:a=n+1,n+2,...,n+m\}$ as the set of existing links with possible actions to be implemented, and $A_3=\{a:a=n+m+1,...,n+2m\}$ as the updated version of set A_2 (after the action is implemented). Links in A_2 and A_3 are numbered such that if $a \in A_2$ is selected, that is, the action associated with it is being implemented, link $a+m$ in A_3 will replace a, otherwise $a+m$ in A_3 will be discarded.

Denoting k as the path and K_ω as the set of all paths in the network connecting the origin-destination (OD) pair ω, where all OD pairs belong to the set Ω, and assuming user type i belongs to the set I with p types of users, then $f^i_{k\omega}$ can be defined as the flow of user type i on path k connecting ω, and x^i_a can be defined as the flow of user type i on link a. The following link flow conservation should then hold:

$$x^i_a = \sum_{\omega\in\Omega}\sum_{k\in K_\omega} f^i_{k\omega}\delta^i_{ak\omega}, \forall a\in A, \forall i\in I \quad (1)$$

where

$$\delta^i_{ak\omega} = \begin{cases} 1, \text{ if path } k \text{ connecting } \omega \text{ for user } i \text{ uses link } a \\ 0, \text{ otherwise} \end{cases}$$

Representing q^i_ω as the demand associated with OD pair ω, then the following OD flow conservation and non-negative path flow should also hold:

$$q_{\omega}^{i} = \sum_{k \in K_{\omega}} f_{k\omega}^{i}, \forall \omega \in \Omega, \forall i \in I \quad (2)$$

$$f_{k\omega}^{i} \geq 0 \quad (3)$$

We then define the set of possible combinations of action Y associated with A_3, that is, $Y = \{y = (y_{n+m+1},...,y_{n+2m}) \mid y_a=0 \text{ or } 1\}$, where Y is the set of combination of actions, and y_a is the action implementation indicator which has a binary value of 1 if the action related to link a on the set of A_2 and A_3 is implemented, and 0 if it is otherwise.

The selection is based on the ratio of reduced total generalised cost and investment 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 advantage of using BCR value, instead of just total network generalised cost, is that this parameter can assess not only the relative improvement (compared to initial conditions) of a combination of actions, but also how effective the combination is. Furthermore, it can also inspect the occurrence of the Braess' paradox (see [1]), i.e. those combinations of capacity expansion that increase the total user cost.

Denoting x^{i*}_{oa} as the equilibrium link flow for user type i in all the initial links, c^{i}_{a} as the generalised link cost function on link a, and F as the set of user types for freight transport, then G_o, the total generalised cost of the initial network without any action implemented can be formulated as follows:

$$G_o = \sum_{i \in F} \sum_{a \in A} x_{oa}^{i*} c_a^i (x_{oa}^{i*}, y_a) \quad (4)$$

Here, y_a equals zero, as any action is not implemented yet.

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. The following objective function $z(y)$ can therefore be formulated:

$$\underset{y \in Y}{maximise} \quad z(y) = \frac{G_o - \sum_{i \in F} \sum_{a \in A} x_a^{i*} c_a^i (x_a^{i*}, y_a)}{\sum_{a \in A_3} b_a y_a} \quad (5)$$

where

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

$c_a^i(x_a^{i*}, y_a)$: generalised cost on link a by user type i that depends on the equilibrium flow and whether the actions are being implemented or not (action implementation indicator y_a) (Rp)

b_a : investment cost of link, if corresponding action is being implemented (Rp)

Wardrop's user optimal principles state that the flow is distributed on the network such that the travel costs on all used routes between origin and destination are equal, while all unused route have equal or greater travel costs. Dafermos [2] recognized these UE conditions to be a variational inequality problem. In the case when the Jacobian matrix of the link cost function is symmetric, UE flow may be obtained as the solution of an equivalent convex cost minimisation problem.

In this paper, 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:

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

$$\sum_{i=1}^{p} c_a^i(\tilde{x}^*) \times (x_a^i - x_a^{i*}) \geq 0, \forall \tilde{x} \in \kappa, \forall a \in A \quad (6)$$

where $\tilde{x}$ is a p-dimensional column vector with the components $\{x_a^1,...,x_a^p\}$ and κ is defined as $\kappa \equiv \{\tilde{x} \mid$ satisfying Equations (1), (2) and (3)$\}$

III. Solution Method

A. General

A bi-level programming approach is employed for solving these problems with the solution process framework shown in Figure 1. The variational inequality problem is solved 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 unavailability 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 [3].

B. Network Representation

A number of link types are used, such as centroid connectors that connect the origin/destination point (centroid)

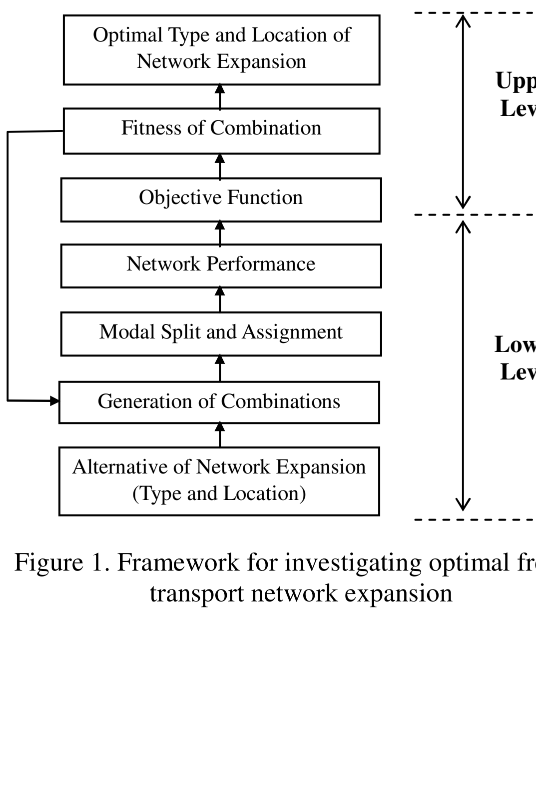


Figure 1. Framework for investigating optimal freight transport network expansion

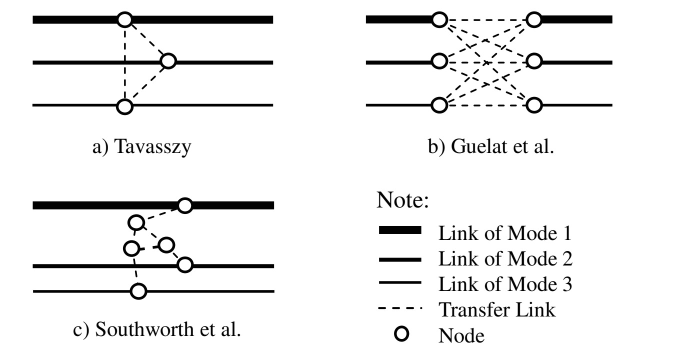


Figure 2. Examples of terminal representations

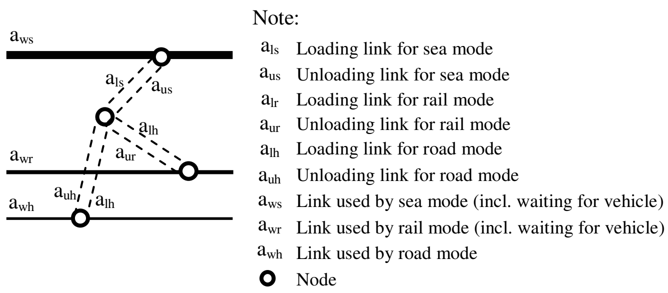


Figure 3. Links representing a multimodal terminal

to the network, link ways that vary among modes and terminal links.

Terminals are very important for freight movements such that it gets special attention in freight network modelling. Tavasszy [4] proposed a simple transhipment link with fixed values of cost and delay time, while Guelat et al. [5] used a more specific transfer link that creates more links in the multimodal terminal. A more explicit representation of terminals in the network proposed by Southworth et al. [6] separates transhipment link into terminal access link and transfer link inside the terminal, although the application is for database and routing purposes only (Figure 2).

To determine the explicit effect of terminals, it is necessary to add more links representing the processes in the terminal. For a three-modal (multimodal) terminal, there would be loading-unloading activities, train spotting and switching, drayage, waiting for vehicles or storage including inspections and other administrative processes. It is necessary, however, to make a simple representation of the terminal to avoid complicated calculation and inputs.

Therefore, the terminal representation in Figure 3 is composed of the unloading link that represents unloading/discharging activity, and storage and loading link that represents loading and other activities in the terminal such as drayage, inspections and other administrative processes. Link way for mode, assumed to have limited vehicle availability for the sea and rail mode, includes waiting for the vehicle activity. Thus, the links can be categorised into centroid connectors, road links, rail links, sea links, loading links and unloading links for each user type. This configuration is used due to the characteristics of the proposed cost and delay functions described in the following section.

C. Link Cost Functions

Cost on link a for user type i (except for the centroid connectors where the cost is neglected) is expressed as a generalised cost composed of a fare component and a time cost component. The time cost component consists of the product of the delay time and time value for each user type.

$$c_a(x_a^i, y_a) = \left(\rho_a^i + \alpha^i \; d_a^i(x_a^i)\right) y_a \tag{7}$$

where

ρ_a^i : fare on link a for user type i (Rp)
α^i : time value for user type i (Rp/hr)
$d_a^i(x_a^i)$: delay time on link a for user type i (hr)
x_a^i : flow on link a for user type i

The fare component is a fixed value and does not depend on volume, while the time cost component, particularly the delay time, is a function of volume and differs by link type. For simplicity, it is assumed that the terminal is a series of (M/M/1) queue system. Therefore, the delay function for loading and unloading is derived from residence time (mean time an item spends in the system) [7] while administration and other processes are considered to be fixed values.

In order to keep the link cost function monotonically increasing, the delay for the administration process is attached to the loading process, while the function for the waiting process is attached to the link ways of sea and rail modes. Therefore, the delay function for the loading link follows Equation (8) and (9), while the delay function for the links used by sea and rail mode follows Equation (10).

$$d_a^i(x_a^i) = \frac{\tau_a}{1 - x_a^i/\psi_a \mu_a} \quad , \forall a \in \textit{unloading links} \tag{8}$$

$$d_a^i(x_a^i) = \theta_a + \frac{\tau_a}{1 - x_a^i/\psi_a \mu_a} \quad , \forall a \in \textit{loading links} \tag{9}$$

$$d_a^i(x_a^i) = \frac{l_a}{S_a} + \frac{\zeta_a}{1 - x_a^i/o_a v_a} \quad , \forall a \in \textit{sea and rail links} \tag{10}$$

where

$d_a^i(x_a^i)$: delay time on link a for user type i (hr)
θ_a : delay time on link a for inspections, administration, drayage, etc. (hr)
τ_a : unloading/loading time on link a (hr)
μ_a : unloading/loading capacity on link a (ton/hr/berth or passengers/hr/ berth)
ψ_a : number of berths on link a (unit)
l_a : travel distance on link a (km)
S_a : average speed on link a for sea and railway links (km/hr)
o_a : frequency of vehicle arrivals on link a (veh/hr)
v_a : average vehicle capacity on link a (ton/veh)

For the links used by the road mode, the delay equation is adopted from the Indonesian Highway Capacity Manual 1997 [8], with the following basic form:

$$d_a^i(x_a^i) = \frac{2t_{oa}}{1 + \left(1 - \dfrac{x_a^i}{r_a}\right)^{0.5}} \quad , \forall a \in \textit{road links} \tag{11}$$

where

t_{oa} : travel time or delay time on link a at flow equal to 0 (hr)

r_a : capacity of road link a (pcu/hr)

The above delay time equations (Equations (8)-(11)) can be used to determine delay time $d^i_a(x^i_a)$ in the cost function $c_a^i(x_a^i,y_a)$ of Equation (5). However, these functions have asymptotic behaviours that require special procedures particularly when the magnitude of flow is about the total capacity, which can lead to a complex objective function.

Therefore, the delay functions are required to be converted to a continuous function. Polynomial approximation proposed by Crainic et al. [9] is used, as follows:

$$d_a^i(x_a^T) = t_0\left[1+\phi_1 x_a^T + \phi_2\left(\frac{x_a^T}{r_a^T}\right)^\gamma\right] \quad (12)$$

where

x^T_a : total flow on link a (veh)

$r^T_{,a}$: total capacity of link a (veh)

ϕ_1, ϕ_2, γ : parameters to be calibrated

Crainic et al. also provided a heuristic method for parameter calibration. Using the value of γ equal to 5 (which gives the best fit among other small integers), and setting x^T_a as $\beta_1 x^1_a+\beta_2 x^2_a$, where β_1 and β_2 are the flow adjustments and x^1 and x^2 are the respective flows of freight and passenger user types, $c_a^i(x_a^i*,y_a)$ can be transformed into the following equation:

$$c_a^i(x_a^i, y_a) = \rho_a^i y_a + \alpha^i t_{0,a}\left(1+\phi_{1,a}\sum_i^p \beta^i x_a^i + \phi_{2,a}\left(\frac{\sum_i^p \beta^i x_a^i}{r_a^T}\right)^\gamma\right) y_a, \quad \forall a\in A \quad (13)$$

By applying this equation to all the links, the multimodal and multi-type links network is then converted to a single abstract mode network.

D. Solution Method for the Lower Level Problem

A method widely used for solving this case of assignment problem is diagonalisation [10]. 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 can simultaneously be undertaken until no significant changes on the flows are obtained. Based on Sheffi [11] and other diagonalisation results in Thomas [12], 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.

E. Solution Method for the Upper Level Problem

The GA-based process is used to randomly generate and evolve the combination of alternative actions on the links, y_a, as well as to create the chromosomes. The value of its objective function is calculated, and its fitness is evaluated.

To attain better calculation performance, the following three schemes relating to GA are investigated:

1. Simple Genetic Algorithm (SGA)

   SGA uses standard operators in reproduction, crossover and mutation. Linear fitness scaling is employed in the reproduction process and single point crossover and creep mutation procedure are adopted.

2. Genetic Algorithm improved with other operators (GA-I)

   Uniform crossover is applied and elitist model is used to preserve some of the best individuals for further generation (e.g. Yamada et al. [13]).

3. Genetic Local Search (GLS)

   The local search operator is inserted after crossover and mutation into the GA-I procedure. The task of this operator is to investigate other two variations of individuals and search the best among them. The variations (new individuals) are produced by determining a random location and then swapping the neighbours.

IV. Application

A. 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.

Currently the share of other-than-road-mode in moving regional freight in Java Island is very low. Based on the national origin-destination survey in 2001, the amount is less than 5% and the movement tends to concentrate on the north roadway corridor, which results in significant impacts on traffic safety and environmental pollutions along the corridor.

Inter-regional freight and passenger movement data (origin-destination matrices) are obtained from the 2001 National OD Survey. Only internal movements between Sumatra and Java are included in the model application. Figure 4 shows the total freight movements exceeding 10 thousand tons per day for all the transport modes in Java Islands.

B. Network and Actions

The transport network is modelled into 86 zones consisting of 352 nodes and 2068 links, comprising the national, toll roads, railways, 10 seaports and port-to-port connections.

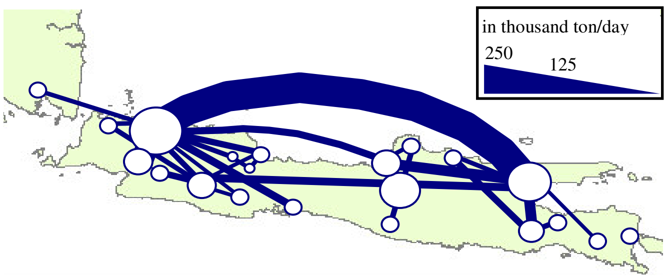


Figure 4. Origin-destination freight movements exceeding 10 thousand ton/day in Java Islands

Parameter values for the links (Equations (8)-(11)) are obtained from statistical data on roads, rails, ports and terminals as culled from various sources. Road capacities and speed data are acquired from the database of the Indonesian Inter-urban Road Management System (IRMS) and the Indonesian toll road operator PT. Jasa Marga. Railway data and related information are obtained from the Department of Communications and the semi-private railway company PT. KAI. Port information and other sea network data are collected from the Directorate General of Sea Communication under the Department of Communications.

The average speed for the rail mode is set at 60 km/hour and at 12 km/hour for the sea mode, and frequency and vehicle capacity values are averaged from the available yearly trip statistics. Capacities for loading/unloading links are derived from the ship handling capacities of several ports/terminals. Other delay times such as time of inspection, inventory, administrations on terminals are assumed, ranging from 6 to 48 hours depending on terminal type. The number of berths is derived from the port's berth length and the average ship length for loading/unloading at sea terminals, while for rail terminals it is equal to the number of yards. The parameters for Equation (13) are then calibrated using $\gamma = 5$ that gives the best fit polynomial result.

There are 16 alternative actions of capacity expansion, which include upgrading or improvement of existing infrastructure and development of new ones for all modes (see Figure 5). Improvements, including road widening, are set on the assumption that the overall capacity is improved 1.5 times the initial capacity. In general, the development of new expressways or toll roads is relatively more expensive compared with the other types, while rail terminal improvement is among the cheapest.

C. 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 [14]), the suitable crossover rate value is 0.6 and the mutation rate value is 0.03 for small to medium cases of genetic algorithm.

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. Overall, the optimal solution only contains an action of number 7 (see Figure 5 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 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 freight network cost, which provides the best total freight network cost improvement.

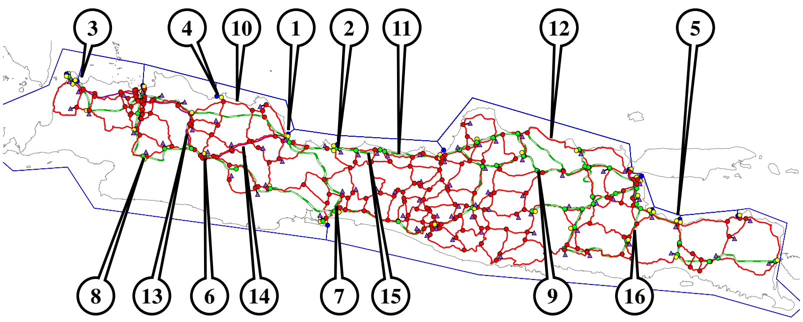
The optimal combination of actions promotes higher mode shares for rail and sea mode when compared with the initial condition. Rail mode share is improved by 1.58% and the sea mode share is improved by 8.12%. This solution also reduces some overloaded road links, especially near the location of action number 7 that occur in the initial condition. This combination is selected because of the relatively low investment cost compared with other alternative actions.

Although the combination with the highest benefit provides a higher 'other than road' mode share with improvement of 5.66% and 19.75% for rail and sea mode, respectively, it requires a relatively high investment cost.

The optimal solution can be found in the 7th generation (see Figure 6) if the GLS procedure is used and the 17th generation if the GA-I procedure is employed. For SGA, the optimal solution has not been reached yet even in the 30th generation. The fast performance of GLS in finding the best combination can be explained by the incorporation of the neighbourhood search within the GA-based procedure, though it requires more individuals to be evaluated (see Figure 7).

The number of evaluated individuals influences the total computational time. The more individuals being evaluated, the higher computational time required. Therefore, within the same number of generation, the SGA procedure requires more or less 1/3 of computational time of GLS.

The average value of the objective function illustrates the convergence level of the GA-based procedures. The procedure can be considered as converging if the average value of the objective function is close to or the same as the highest value of the objective function for each generation. It can be seen from Figure 8 that the GLS procedure has nearly reached convergence after the 20th generation, while other procedures are still far from convergence even in the 30th generation. Therefore, it can be presumed that in this case, the number of generation required is 20 using GLS procedure, while more than 30 generations is required to find the solution and reach an acceptable convergence level for other procedures.



No.	Type of Capacity Expansion	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 5. Test network and alternatives of capacity expansion

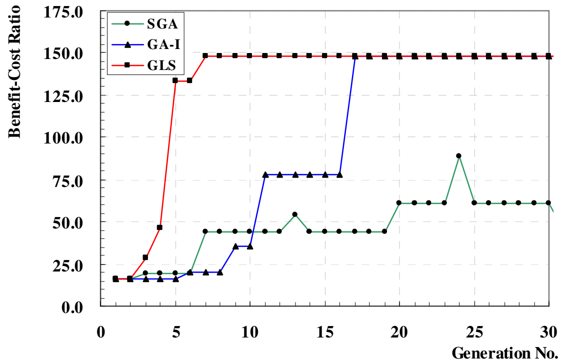


Figure 6. Highest BCR value of each generation

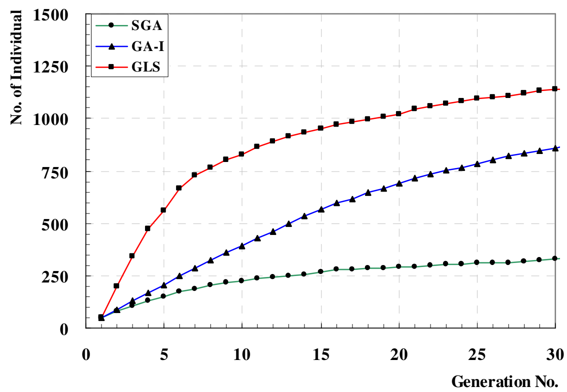


Figure 7. Accumulated number of evaluated individuals

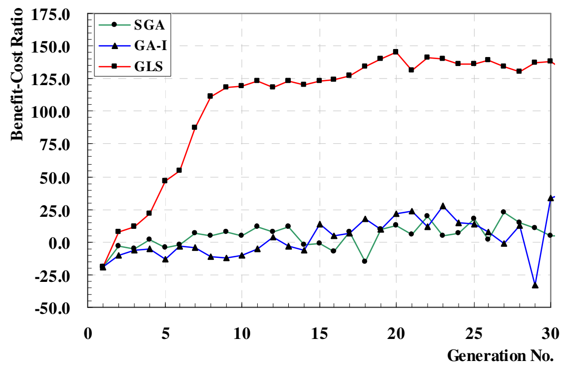


Figure 8. Average BCR value of each generation

Subsequently, if using GLS with 20 generations, the accumulated number of evaluated individuals is 1142, which is 1.74% of the total number of possible combinations of 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 one of the advantages of using this approach.

V. 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. It presented a method for solving discrete network design problem, in this case selecting the best combination of actions for capacity expansion 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. A variation on the GA-based approach is applied on the actual freight transport network in Java, Indonesia.

Results revealed that the model using GLS procedures adequately found the best combination of capacity expansion, with the ratio of sampled individuals and total possible combinations being very low. This procedure also provides a faster convergence but prevents stopping at a local optimal solution.

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

References

[1] Bell, M. G. H., Iida Y. *Transport Network Analysis*, John Wiley & Sons, England, 1997.

[2] Dafermos S. C. *Traffic Equilibrium and Variational Inequality*, Transportation Science 14, pp. 43-54, 1980.

[3] 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.

[4] Tavasszy L. A. *Modeling European Freight Transport Flows*, PhD Thesis, T. U. Delft, 1996.

[5] Guelat J., Florian M. and Crainic, T. G. *A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows*, Transportation Science 24(1), pp. 25-39, 1990.

[6] Southworth F. and Peterson, B. E. *Intermodal and International Freight Modeling*, Transportation Research Part C 8, pp. 147-166, 2000.

[7] Stallings W. *Queueing Analysis,* WilliamStallings.com/ StudentSupport.htm, 2000.

[8] Directorate General of Highway, Department of Public Works, Republic of Indonesia, *Indonesian Highway Capacity Manual*, 1997.

[9] 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.

[10] Florian, M., Spiess, H. *The Convergence of Diagonalization Algorithms for Asymetric Network Equilibrium Problems*, Transportation Research 16B, No. 6, pp. 477-483, 1982.

[11] Sheffi, Y. *Urban Transportation Networks: Equillibrium Analysis with Mathematical Programming Methods*, Prentice Hall, Englewood Cliffs, New Jersey, 1985.

[12] Thomas R. *Traffic Assignment Techniques*, Avebury Technical, England, 1991.

[13] Yamada, T., Taniguchi,E. and Noritake,M.: *Optimal location planning of logistics terminals based on multiobjective programming method*, Urban Transport V, L.J. Sucharov (Ed.), WIT Press, pp.449-458, 1999.

[14] Goldberg, D. E. *Genetic Algorithms in Search, Optimization*, and Machine Learning, Addison-Wesley, 1989.