

# **Multi-Objective Evaluation of Intermodal Freight Terminal Location Decisions**

**ACKCHAI SIRIKIJPANICHKUL**

Ph.D. Candidate  
Queensland University of Technology  
PO Box 2434, Brisbane, Qld 4001  
Phone (617) 3864 1542  
Email: a.sirikijpanichkul@qut.edu.au

**LUIS FERREIRA**

Professor  
Queensland University of Technology  
PO Box 2434, Brisbane, Qld 4001  
Phone (617) 3864 1542  
Email: l.ferreira@qut.edu.au

## **ABSTRACT**

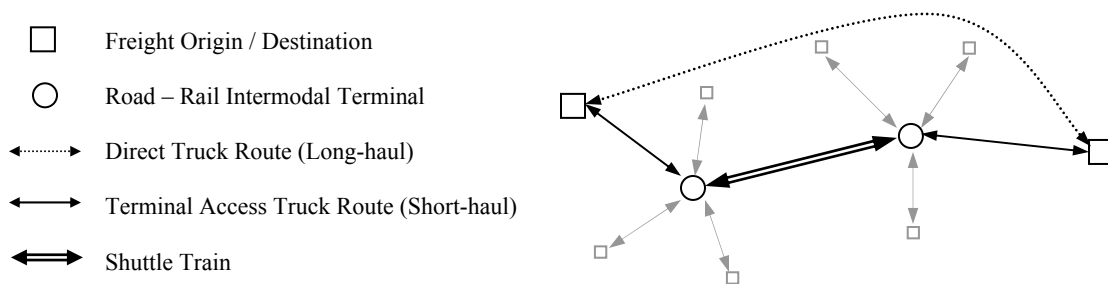
In the movement of freight across the supply chain, terminals play an important role as points of transfer between different modes. The location of terminals is one of the most crucial success factors bearing directly and indirectly on the main stakeholders involved including policy makers, investors, terminal operators, freight operators, and the local community affected. There have been several attempts to develop models to evaluate the optimum location of terminals. However, those models tend to maximize terminal owners' and users' benefits. Only a few attempts have been made to include community impacts.

There is a need to deal with the individual perception and strategic behavior of each stakeholder, including the behaviour and objectives of the impacted community living close to potential terminal sites. Finally, there is no concrete study on how terminal expansion, interdependency of terminals, and freight policy affect the pattern of terminal locations. The paper reports on the initial phases of a study aimed at developing a model to perform an evaluation of intermodal freight terminal location decisions. The model will be developed, based upon the most appropriate multi-objective evaluation techniques derived from the findings of the research investigation, with other supporting established modules including land use allocation and transport network models; financial viability; terminal user cost; and environmental and traffic impact modules. The influences of terminal expansion, interdependency of terminals, and freight policy on the pattern of terminal locations will also be investigated by a sensitivity test. The developed model is expected to be a comprehensive tool for assisting decision makers in selecting the optimum terminal locations that satisfy the often conflicting needs of the major players.

## 1. INTRODUCTION

Intermodal freight transportation is defined as a system that carries freight from origin to destination by using two or more transportation modes. This research is limited to road-rail intermodal freight transportation which is competitive with road only options over longer distance and characterised by the combined advantages of rail and road, mainly: a rail for long distances and large quantities, road for collecting and distributing over short or medium distances, Nierat (1992); Slack (1998); and Arnold et al. (2004).

Intermodal freight terminals are one of the key elements that function as transferring points of freight from one mode to another (See **Figure 1**.) The term “terminals” will be used throughout this paper.



**Figure 1 Road – Rail Intermodal Terminal**

Location of terminals is one of the most crucial success factors in intermodal freight transportation and needs to be considered very carefully as it has direct and indirect impacts. For example, financial, economic, social, and environmental impacts on different stakeholders involved including investors, policy makers, freight terminal operators, freight operators, industry, and the community.

## 2. LITERATURE REVIEW

This research deals with multi-objective evaluation of road-rail intermodal freight terminal location. In this section, background of intermodal freight terminals, terminal location decisions, objective functions and criteria for evaluation, optimisation models for location decisions, multi-objective evaluation as well as the current state of knowledge in design of multi-objective terminal location evaluation models are reviewed.

### 2.1 Intermodal Freight Terminals

Characteristics of terminals are described by McCalla et al. (2001) as: transfers of freight from one mode to another; requiring large amount of land and a high degree of accessibility; having a low rental which is affordable by every user; and generating negative environmental impacts especially noise and traffic congestion, Slack et al. (1997). Types of the terminals can be classified by different criteria (see **Table 1**).

**Table 1 Classification of Intermodal Freight Terminals**

Classification Criteria	Types	Remarks
Connector,	<ul style="list-style-type: none"> <li>- Ports (ocean and river)</li> <li>- Airports</li> <li>- Road/rail terminals</li> <li>- Pipeline/road terminals</li> </ul>	
Size, Sd+D (2004)	<ul style="list-style-type: none"> <li>- Small</li> <li>- Medium</li> <li>- Large</li> <li>- Super</li> </ul>	<ul style="list-style-type: none"> <li>- less than 5,000 TEU's<sup>1</sup></li> <li>- 5,000 to 20,000 TEU's</li> <li>- 20,000 to 40,000 TEU's</li> <li>- over 40,000 TEU's</li> </ul>
Organisation, RFG (2005)	<ul style="list-style-type: none"> <li>- Single customer terminals</li> <li>- Single operator terminals</li> <li>- Independent service providers (3th party logistics operator)</li> <li>- Freight villages</li> <li>- Other sidings</li> </ul>	

Source: Adapted from Sd+D (2004) and RFG (2005)

## 2.2 Terminal Location Decisions: Influencing Factors

Intermodal freight terminals have direct and indirect impacts on land use and business development, McCalla et al. (2001). A number of factors influencing terminal location decisions can be viewed from different perspectives, as shown in **Figure 2**.

In a terminal user's or *demand* perspective, the major determinants include proximity to industries; market; and Central Business District (CBD), rental costs and types of intermodal freight; containers and vehicle characteristics, McCalla et al. (2001). For a terminal owner/operator or *supply* perspective, site and space, access to transportation infrastructure (e.g. truck routes, railway lines, port etc.), and accessibility are the predominant ones, West and Kawamura (2005). Apart from *direct* influencing factors as mentioned above (in both demand and supply perspectives), *indirect* factors exist. For instance, externalities need to be taken into account from a *community* perspective. McCalla et al. (2001) pointed out that although influences of industrial firms, as well as other location determinants, on the financial viability of the terminal are mentioned; specific values still cannot be assigned to transport impacts as the spatial proximity of a company to a transport site does not imply a direct or induced effect.

From the literature review, many impacts especially externalities have still not been fully evaluated. *Externalities*, for example, environmental impacts, energy usage impacts, and social impacts, are explained as the impacts felt by those who are not transport users (ie: third parties who are not compensated if it is a cost; or asked to pay if it is a benefit), Sirikijpanichkul and Ferreira (2005).

A challenge is how to incorporate these externalities into the current terminal location decision studies. The behavior of various groups of land users, e.g. residential, commercial, etc., also need to be considered in order that equitable solutions are arrived at. Some determinants may have more weight for specific groups. For instance, local residents may be more concerned about

<sup>1</sup> TEU - Container dimension means twenty-foot equivalent unit (or 6.2 meters in length)

environmental health than terminal users. Thus, it is important to balance the benefit among the relevant parties.

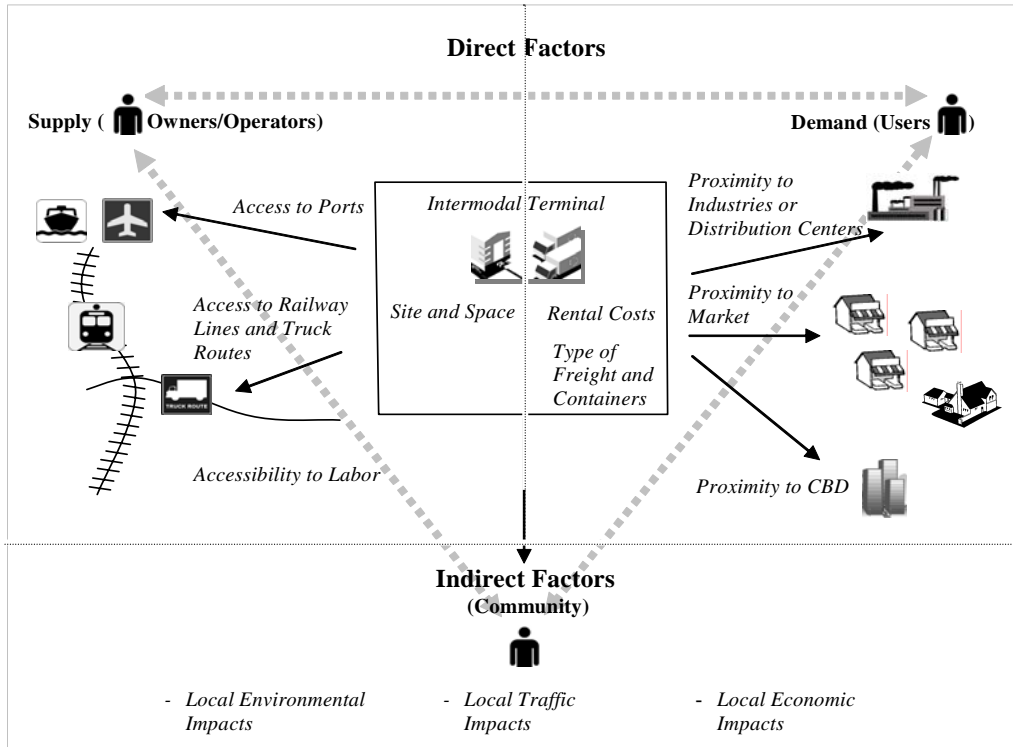


Figure 2 Intermodal Freight Terminal Location Decisions: Influencing Factors

### 2.3 Objective Functions and Criteria for Evaluation

To evaluate terminal location options, all relevant criteria should be determined according to the aims and goals of each stakeholder. The criteria define the measure of performance that will be produced by the model. To measure the effectiveness of these criteria, the objective function and the decision variables are required. In addition, the constraints, which represent resource limits, unacceptable system outputs, need to be defined to ensure that the decision variable are restricted to their feasible (or permissible) values, Taniguchi et al (2001). Basically, in solving the location decision problem, the objective function is developed to minimise the total costs or maximising the total benefits. The simplified objective function is expressed as

$$\max_{x \in X} f(x) = (TC' - TC(x)) / \sum_i C \cdot T_i \quad \dots (1)$$

*Inputs:*

- i: number of candidate terminals
- c: unit cost of freight operation (\$/ton or container unit)
- T: amount of freight operated at terminal I (ton or container unit)
- X: feasible sets of vector x
- TC, TC': total transportation costs with and without terminals, respectively (\$)

*Decision Variables:*

- x: vector of location patterns of candidate terminals

Subject to (*Constraint Function*):

$$g(x) \leq b_i \quad \dots (2)$$

A series of objective functions has been developed to represent the most realistic characteristics of intermodal transportation costs. The latest objective function has been developed by Racunica and Wynter (2005), using a non-linear, mixed-integer program based on the uncapacitated terminal location problem expressed as:

$$\min_{x, \hat{x}, hh, hd, z} \psi(x, hh, hd) + \sum_{(i,l) \in W \setminus (H \times H)} \hat{c}_{il} \hat{x}_{iil} + \sum_{j \in H} f_j z_j \quad \dots (3)$$

The costs ( $\psi$ ) in the linearised objective function are expressed as

$$\psi(x, hh, hd) = \sum_{i \in N} \sum_{j \in H} c_{ij} \sum_{k \in H} \sum_{l \in N} x_{ijkl} + \sum_{j \in H} \sum_{k \in H} a_{jk}^1 \sum_{m=1, \dots, M} \phi_m^{hh} hh_{jkm} + \sum_{k \in H} \sum_{l \in N} a_{kl}^2 \sum_{m=1, \dots, M} \phi_m^{hd} hd_{klm} \quad \dots (4)$$

where

- $i, l$  : origin and destination, respectively;
- $j, k$  : origin and destination terminal, respectively;
- $x$  : freight volume;
- $hh, hd$  : binary variables to represent to flow between each kink in the piecewise-linear approximation where  $hh, hd = 1$ ; if the  $m^{\text{th}}$  portion of flow is captured by the terminal shuttle service between terminals  $j$  and  $k$ ; for  $m = 1; \dots; M$  and 0 otherwise;
- $c(x)$  : variable cost (see **Figure 3**);
- $\hat{x}_{iil}$  : flow on the direct path from  $i$  to  $l$ ;
- $H \subseteq N$  : set of potential terminal nodes;
- $W \subseteq N^2$  : set of origin-destination pair
- $f$  : fixed cost at the terminal;
- $z$  :  $z = \{z_j\} \in \{0, 1\}^{|H|}$  is the vector of binary decision variables indicating whether a terminal is to be opened or not;
- $a$  : travel time derived from

$$a \left( \sum_{(i,l) \in W} \bar{x}_{ijkl} \right)^b = \bar{c} \sum_{(i,l) \in W} \bar{x}_{ijkl} \quad \dots (5)$$

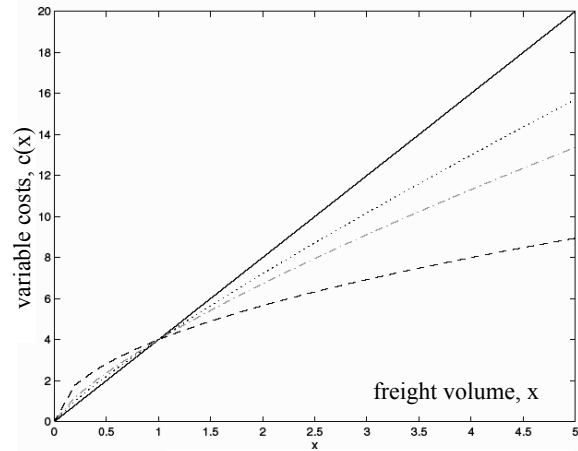
(See **Figure 4**)

- $d$  : the vector of the demands for transport  $d = \{d_{ii}\} \in \mathfrak{R}_+^{|W|}$

$$\phi_m^{hh}, \phi_m^{hd} : \phi_m^{hh} = m^{0.5} - (m-1)^{0.5}, \quad \dots (6)$$

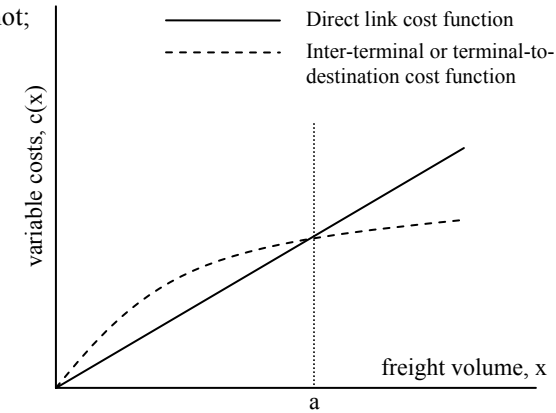
$$\phi_m^{hd} = m^{0.6} - (m-1)^{0.6} \quad \dots (7)$$

the slopes of each linear unit-length piece of the functions  $c_{jk}^1(\cdot)$  and  $c_{kl}^2(\cdot)$ , respectively.



Source: Racunica and Wynter (2005)

**Figure 3 Inter-terminal Discount Function**



Source: Racunica and Wynter (2005)

**Figure 4 Cost function calibration between a direct and terminal-based trip**

## 2.4 Optimisation Models for Location Decision

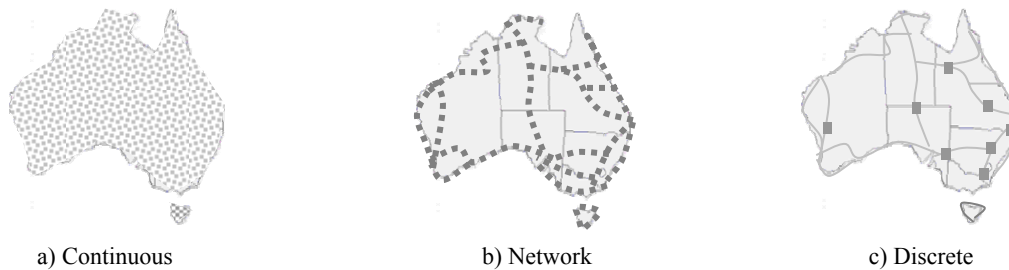
Optimisation models are normally used when the *best* or *optimum* solutions of the objective functions in a specified system are required. Basically, these models fall into two categories; namely, *classical* and *heuristic* (see **Table 2**).

**Table 2 Categories of Optimisation Techniques**

Category	Techniques and Applications	Advantage	Disadvantage
A) Classical	<ul style="list-style-type: none"> <li>- Mathematical programming:                             <ul style="list-style-type: none"> <li>• Linear / non-linear programming</li> <li>• Simplex method</li> </ul> </li> <li>- Branch and bound algorithms,</li> <li>- Lagrangian relaxation,</li> <li>- Branch and cut methods,</li> <li>- Set partitioning formulations, Etc.</li> </ul>	<ul style="list-style-type: none"> <li>- Provide the <i>exact</i> solution</li> </ul>	<ul style="list-style-type: none"> <li>- Limited to small scale simplified problems.</li> <li>- Require many simplified assumptions</li> <li>- High computation cost.</li> </ul>
B) Informed (heuristic) search strategies	<ul style="list-style-type: none"> <li>- Hill-climbing search,</li> <li>- Simulated annealing search,</li> <li>- Local beam search,</li> <li>- Tabu search,</li> <li>- Genetic algorithms,</li> <li>- Expert system,</li> <li>- Neural network,</li> <li>- Fuzzy control system,</li> <li>- Multi-agent system, Etc.</li> </ul>	<ul style="list-style-type: none"> <li>- Practical for complex model formulations.</li> <li>- Flexible regarding to the nature of the objective function and constraints.</li> <li>- Reasonable computation cost.</li> </ul>	<ul style="list-style-type: none"> <li>- Do not guarantee to find the <i>exact</i> solution.</li> </ul>

Source: Adapted from Taniguchi et al (2001) and Russell and Norvig (2003).

Location models can be distinguished not only by type of objective function but also by the attitude taken towards the choice of location. Basically, they fall into three categories, namely, *continuous*, *network*, and *discrete* models (see **Figure 5**).



**Figure 5 Continuous, Network, and Discrete Location Models**

The continuous model basically assumes that the facility may be located anywhere in the space, whereas the network model considers all the potential locations on the transport network. The last model is the discrete model where a list of pre-selected sites is required from which to choose the best alternative set.

### 2.4.1 Classical Models

A number of researchers have applied classical techniques and network models to determine the optimum number, size, and location of terminals, as well as the overall performance of the system, including *quadratic integer programming*, O’Kelly (1987) and Klincewicz (1991), *linear programming* and *binary* terminal-opening variables, O’Kelly et al. (1995); Klincewicz (1996); Skorin-Kapov et al. (1996); Ernst and Krishnamoorthy (1998); Nickel et al. (2000); Sohn and Park (2000) and Hamacher et al. (2000), *linear programming* (total transport costs), Arnold and Thomas (1999), *non-linear programming* in which the inter-terminal cost term is a *concave* increasing function of flow, O’Kelly and Bryan (1998) and Guldmann and Shen (1997), *non-linear, mixed-integer program* based on the *uncapacitated terminal location problem* including non-linear terms on the final terminal-to-destination links and inter-terminal links (take into account the effect of *freight consolidation* and their *scale economies*), and a non-linear function (concave cost functions) to capture the *efficiency threshold* of the inter-terminal and terminal-to-destination links, a variable-reduction heuristic is also developed and used in the model, Racunica and Wynter (2005).

A *discount factor* is applied to incorporate the cost reduction effect according to the consolidation process in Ernst and Krishnamoorthy (1998); Hamacher et al. (2000), O’Kelly et al. (1995); or Skorin-Kapov et al. (1996), and the number of *profitable* terminals (in term of opening costs and travel time saving) to be opened and the paths used in the network are analysed in Bryan and O’Kelly (1999); Campbell (1994, 1996),

Although, the model developed by Racunica and Wynter (2005) is the latest classical model developed to date, it still has limitations. For example, explicit capacity constraints on the terminals and shuttle and direct block services were not included in this model. Time-of-day through a dynamic model and differentiation of freight flows by product type are not taken into account. Fixed costs of converting existing terminals and marshaling yards into mega-terminals are difficult to obtain, so the authors use only high, medium, and low estimates for these costs, rather than quantifying them. In order to model the influence of train frequency on choice decisions and on travel costs, the authors chose to implicitly include frequency effects through a calibration of the cost function, rather than through the use of a dynamic model with time as a parameter, similar to frequency network design as classified by Crainic (2000). Finally, externalities are not involved. Also the recommendations which need attentions include the investigation of the use of non-linear programming techniques, such as non-linear column generation, to obtain good lower bounds in conjunction with some upper-bounding scheme, a comparative study of the proposed heuristic with other techniques such as linear programming-based methods, and finally further work on the polyhedral properties of the problem would be useful for medium and large size problems.

Hamacher and Nickel (1998) propose a general classification that can be used to describe all classical location models. It is in the form of  $P_1/ P_2/ P_3/ P_4/ P_5$  where each position refer to the number and type of new facilities, type of the location model, a description of particulars of the specific location model, relation between new and existing facilities, and description of the objective function, respective. For example,  $N/D/. / \sum$  and  $\#/D/. / \sum$  define the discrete N-median model and the uncapacitated facility location model (UFL).

Solution methods to be used in terminal location decision problems classified by type of model are reviewed in **Table 3**

**Table 3 Solution Methods in Terminal Location Decision Problems Classified by Type of Location Model**

Type of Model	Techniques used
Linear Location Model	<ul style="list-style-type: none"> <li>- A Benders decomposition and the 0-1 programming problem over the binary variables.</li> <li>- Specialized heuristics – Klineciewicz (1991)</li> <li>- Meta-heuristics such as tabu search – Skorin-Kapov and Skorin-Kapov (1994)</li> <li>- Dual procedures</li> <li>- Linear programming relaxation – Klineciewicz (1996), Skorin-Kapov et al. (1996)</li> </ul>
Convex Non-Linear Location Model	<ul style="list-style-type: none"> <li>- Benders scheme</li> <li>- Lagrangian heuristics to obtain good lower bounds</li> <li>- Branch and bound from the dual solutions to obtain very good or exact primal solutions</li> </ul>
Concave Non-Linear Location Model	<ul style="list-style-type: none"> <li>- A path flow exchange-type algorithm based on repeated shortest path calculations and shifts of flow across the shortest paths - Minoux (1989)</li> <li>- Upper and lower-bounding procedures – Balakrishnan and Graves (1989)</li> <li>- Randomized meta-heuristics GRASP – Holmqvist et al. (1998)</li> <li>- Specialized heuristic by successive linear underestimation of the piece-wise-linearized cost function.</li> <li>- Algorithms for the exact solution over polytopes – Horst and Tuy (1996)</li> <li>- A standard mixed-integer facility location problem – Verter and Dincer (1995)</li> <li>- A standard mixed-integer linear programming software – O’Kelly and Bryan (1998)</li> <li>- A single, large mixed-integer program – Hamacher et al. (2000)</li> </ul>

Source: Adapted from Racunica and Wynter (2005)

### 2.4.2 Heuristics Models

The other alternatives to be used for terminal location decision problems are *heuristic* techniques. By their nature, heuristic approaches are flexible regarding the nature of the objective function and constraints. Many heuristics use the concept of neighbourhood when generating solutions. A neighbourhood is the set of solutions that can be formed the current solution by a simple operation. The nature of the problem usually determines how the neighbourhood set is constructed, Taniguchi et al (2001). As *heuristic* techniques are widely used in solving multi-objective optimisation problems, they will be reviewed intensively in *Multi-objective Evaluation* section.

### 2.5 Multi-objective Evaluation

Before the multi-objective evaluation model is established, it is necessary that the system boundaries or limits of the systems should be set up. These system boundaries generally have 3 dimensions A) spatial: geographic boundaries (where?); B) stakeholders: population groupings (who?) and C) impacts: range of effects (what?). Of all dimensions, stakeholders seem to be the most complicated component that cannot be solved straightforwardly in the modelling process. Generally, stakeholders (actors) reason from their own subjective. Those perceptions are possibly incomplete or even incorrect. Therefore, perception based modelling techniques are developed and expected that they will help the decision-making process become closer to reality, Taniguchi et al. (2001). In the terminal location decision problem, there are a number of stakeholders

involved. The aims and goals of each stakeholder, as shown in **Table 4**, can easily be in conflict. To deal with this problem, all the criteria are necessary to be converted into measurable indicators and evaluated by using multi-objective evaluation models.

**Table 4 Objectives and Criteria for Terminal Location Evaluation Model**

Stakeholder	Actors	Objectives and Criteria for Evaluation
A) The users	<ul style="list-style-type: none"> <li>- Transport operators;</li> <li>- Forwarder;</li> <li>- Consignors and consignees</li> </ul>	<ul style="list-style-type: none"> <li>- The logistical (operational) desirability:                             <ul style="list-style-type: none"> <li>• The minimisation of the cost of transport (The sum of the “out-of-pocket” cost and the value of the transportation time);</li> <li>• The reliability and the frequency of the service;</li> <li>• The services offered by the terminal;</li> <li>• Connection with other transport modes;</li> </ul> </li> </ul>
B) The service providers	<ul style="list-style-type: none"> <li>- The terminal owners;</li> <li>- The terminal operators</li> </ul>	<ul style="list-style-type: none"> <li>- Financial viability and sustainability;</li> <li>- The possibility to expand the terminal;</li> <li>- The capacity of the system</li> </ul>
C) The community as a whole		<ul style="list-style-type: none"> <li>- The environmental impacts,</li> <li>- The traffic impacts,</li> <li>- The economics impacts: cost/benefit analysis</li> </ul>

Source: Adapted from EU (1996) and Macharis (2001),

A series of multi-objective evaluation models is developed. Rutten (1995) constructs a *network model* of the road-rail network in the Netherlands. The model determines the effect of adding new terminals to the system on the existing ones and on the overall performance of the system. EU (1996) provides an overview of the evaluation methods and criteria used in investment decisions for terminals in the various EU countries. An integrated framework for the evaluation of nodal centers, where a financial analysis and a social cost/benefit analysis are combined, is proposed. However, it is difficult to be used as all the effects have to be expressed in monetary-values.

Ashayeri and Rongen (1997) propose a framework to select a site for a European Distribution Center (EDC). A model is proposed to select the optimal sites according to the cost minimisation criterion (cost of transport and location). The number of sites resulting from the model determines the type of distribution model (centralized versus decentralized distribution). If there is a lack of data, a grid model is used. The final evaluation is done by *ELECTRE* method. Maggi (1998) determines the decision criteria for location of logistics nodes but no formal evaluation method is developed. Macharis (2001) points out that the studies of Ashayeri and Rongen (1997) and Maggi (1998) are not applicable to the location of intermodal terminals due to the different kind of criteria that have to be considered when the size of the projects is much larger. Accordingly, the “*LAMBIT*”-model (Location Analysis Model for Belgian Intermodal Terminals) by the *PROMETHEE*-method, Brans (1982); Brans and Mareschal (1994); Macharis et al. (1998), by using Decision Lab software, Visual Decision (1999), is developed in his study. However, the study only focuses on the location of an inland intermodal terminal at a waterway which may have different characteristics for road-rail intermodal terminal in different aspects.

Declercq and Verbeke (1999) develop a decision support system called *EMOLITE*: the Evaluation Model for the Optimal Location for Intermodal Terminals in Europe is developed by using *fuzzy logic*. It also incorporates a simulation facility, where the user can compare what are the results are of changes in his/her weights in the ranking of terminals. However, a number of limitations are found. The model is considered as a prototype rather than a practical tool. It ranks the alternative terminals according to a number of attribute values and criteria which have influence on investors and users but not on community (externalities are ignored). Distances between terminals are not considered. The origin terminal is not relevant, only the destination terminal, its conditions and the connections it has with other terminals is considered. Also Intermediate terminals are not integrated. Finally, the multiple terminal choice models are not implemented in the model due to its complexity. Groothedde and Tavasszy (2000) use the *simulated annealing* technique. In order to find the optimal locations of terminals, terminals are added to the network randomly and for each changed network configuration the total generalized and external costs are determined.

From the literature review, some arguments are made and need attention. Intermodal terminal location is not only the matter of terminal operators' or users' benefits, but also community's benefits as a whole. In most studies, externalities including social and environmental costs are largely neglected. There are very limited researches that incorporate these externalities e.g. Groothedde and Tavasszy (2000). To select the optimum location for all of the stakeholders, understanding the 'real' perception of each actor (e.g. operators, users, and community) including the individual strategic behavior is very important. There is still lack of understanding in these aspects. Some investigations have been made e.g. *DANA* in Taniguchi et al. (2001) but they are rather qualitative instead of quantitative.

Multi-objective optimisation/evaluation is applied to solve terminal location evaluation problems. Heuristic approach is found to be more practical to deal with such a complex situation than classical one. In addition, it is more flexible and cost effective. Several heuristic techniques have been used in the intermodal terminal location evaluation problems including *fuzzy logic*, Declercq and Verbeke (1999), *simulated annealing*, Groothedde and Tavasszy (2000), and *PROMETHEE*-method, Macharis (2001). Some techniques, although have not directly been used in solving the terminal location problems, but are challenging to be adopted, for instance, *beam search algorithm*, Kim and Kim (1999), *tabu search*, Preston and Kozan (2001); Higgins et al. (1996), *expert system*, Abacoumkin and Ballis (2004), *genetic algorithms*, Bontempi et al. (2005); Bortfeldt and Gehring (2001); Kozan (1997, 2000); Kozan and Preston (1999); Bruzzonea and Signorile (1996); Gambardella et al. (1996), and *multi-agent system*, Brooke (2002); Degano and Pellegrino (2002); Degano et al. (2001); Dong and Li (2003); Funk et al. (1998, 1999); Gambardella et al. (2001), Henesey (2002, 2004a, 2004b); Henesey (2003a, 2003b); Mastrolilli et al. (1998); Proshun (2003); and Rizzoli et al. (1999, 2002). However, there is no literature comparing the performance of these evaluation techniques so far.

The other argument that needs to be addressed is, even the network model plays an important role when solving the terminal location problem as it determines the effect of adding new terminals to the system on the existing ones and on the overall performance of the system, the influence of terminal expansion, interdependency of terminals (how they really work together), and freight policy on the pattern of terminal locations have never been critically investigated to date. According to the arguments made above, the authors believe that there is still considerable room to improve the existing models being used in solving the intermodal terminal location evaluation problem.

### 3. PROBLEM STATEMENT

A number of research questions emerge from the literature review. For example, a) when evaluating terminal location decisions, are all the stakeholders' benefits fully taken into account? b) Does the model truly reflect the 'real' perception of each stakeholder (e.g. operators, users, and community) and the individual strategic behavior? c) Which techniques are most appropriate for evaluating terminal location decisions? d) How terminal expansion, interdependency of terminals (how they really work together), and freight policy affect the pattern of terminal locations? How to measure these influences?

### 4. OBJECTIVES

The objectives of this research is to develop a terminal location evaluation model, which takes all the stakeholders' benefits into consideration, to investigate the individual perception and strategic behavior of each stakeholder and incorporate them into the model, review and discuss the advantages and disadvantages of each evaluation technique and adapt one that is likely the best to be used in the model, and finally to investigate the influences of terminal expansion, interdependency of terminals, and freight policy on the pattern of terminal locations and measure them through the sensitivity analysis.

### 5. TERMINAL LOCATION EVALUATION MODEL

After the advantages and disadvantages of various multi-objective optimisation techniques, in both classical and heuristic approaches, are evaluated and compared, the most appropriate model will be selected to develop the terminal location evaluation model. The model comprises four supporting modules including land use allocation and transport networks; financial viability; terminal user costs; and environmental and traffic impacts. These modules are developed to ensure that all of the stakeholders' benefits (including terminal owners' / operators', terminal users', and communities') are taken into account. Objective functions, evaluation criteria, and constraints of each stakeholder will be developed and incorporated into the model.

*Land use allocation and transport network module* will be developed by incorporating *transport network data* including zones (residential and commercial areas; major trip attraction and destination; industrial parks; ports; etc.); links (road; rail; expressway; etc.) and nodes (intersections; interchanges; intermodal terminals;, etc.) and their attributes; for instance, capacity; speed-flow curve; types of intersection control; signal setting; priority rules; penalty functions; etc., *transport demand data* including Origin-Destination (O-D) matrix, especially in peak-hour periods, of both passenger and freight, and *transport policy data* including all of the transport policies implemented especially freight transport policy e.g. zonal or temporal truck ban; truck routes etc.

*Financial viability module* will be developed by incorporating *terminal cost data* including capital; operation; and maintenance cost of the terminals, *terminal revenue data* including rental fee and other revenues generated from terminal operation, and *indicators for sustainability data*

including volume; distance; site investment; import/threat of competing channels; terminal capacity and capital equipment; and seasonality, Sd+D (2004).

*Terminal user cost module* will be developed by incorporating *terminal user cost data* including operation cost; vehicle operating cost; delay cost; out-of-pocket cost e.g. terminal fee; toll fee etc.

*Environmental and traffic impact module* will be developed by incorporating *emission data* including emission factors of major emissions e.g. Carbon Monoxide (CO); Nitrogen Oxide (NO<sub>x</sub>); Sulphur Dioxide (SO<sub>2</sub>); Suspended Particulate Matter (SPM); etc., and quantifying value of each emission; *noise data* including noise impact factor and its quantifying value; *traffic impact data* including value of time and vehicle operating cost of transport users.

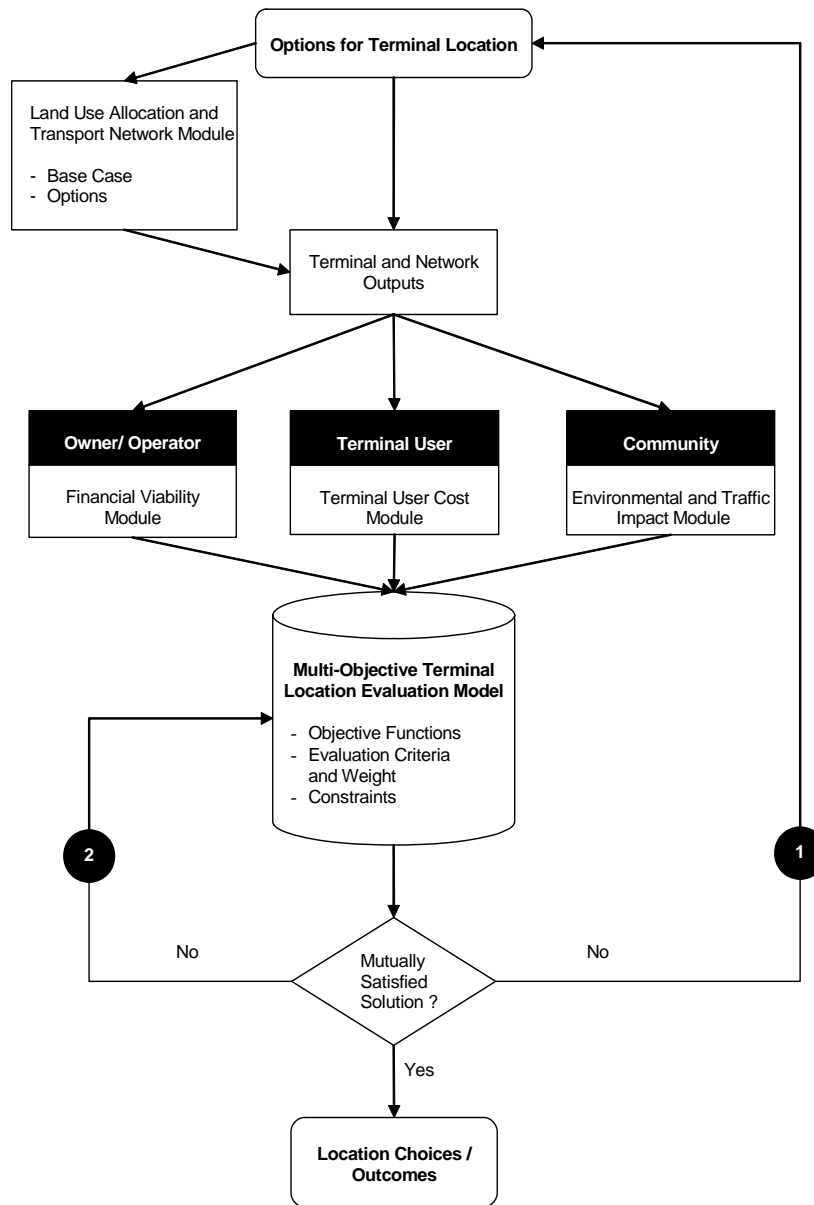
The model process begins with the options for terminal location being sent to land use allocation and transport network module as input data. Then, the terminal and network outputs of base case and options are calculated including terminal costs (capital costs; terminal operating; and other variable costs) costs, traffic volume, vehicle-kilometer-travel (VKT) etc. These output data are then supplied into financial viability module, terminal user cost module, and environmental and traffic impact module to calculate the evaluation attributes to be used in multi-objective location evaluation model. After the multi-object location evaluation process, if the solution is mutually satisfied by all of the stakeholders then the location choices become the final outcome, else the feedback would be sent back either to the options for terminal locations to re-select another set of location choices or to the multi-objective location evaluation model to negotiate among the stakeholders and re-adjust the weight of each stakeholder. The structure of terminal location evaluation model is illustrated in **Figure 6**.

## **6. MODEL TESTING AND VALIDATION**

To assure that the model is calibrated and validated, it will be tested with a real-world case study. In this research, the potential sites of intermodal freight terminals in SEQIFTS, according to the Stage 2 of South East Queensland Inter-modal Freight Terminals Study (SEQIFTS) report, QT (2005), will be used as a case study. The model will be calibrated and validated against set of validation data. To investigate the influences of terminal expansion, interdependency of terminals, and freight policy on the pattern of terminal locations, sensitivity test will be conducted to the model by observing changes of model outputs subject to changes of the relevant variables.

## **7. EXPECTED OUTCOMES**

The model developed from this research work, is expected to be a comprehensive tool for assisting decision makers in selecting the optimum terminal locations that satisfy all needs of stakeholders. The model will take into account the perception of each stakeholder, as well as the individual strategic behavior, the interdependency of terminals, and the influence of freight policy on the pattern of terminal locations.



**Figure 6 Evaluation Model for Intermodal Freight Terminal Location**

## 8. CONCLUSION

This research is aiming at developing a new evaluation tool for intermodal freight terminal locations since the previous models are not inclusive in terms of externalities, stakeholders' perception and behavior, model appropriateness, and impacts of terminal expansion; interdependency of terminals; and freight policy. The paper provides the approaches that the model is developed and the comprehensive literature reviews on the relevant topics.

## REFERENCES

- Abacoumkin, C. and Ballis, A. (2004). Development of an expert system for the evaluation of conventional and innovative technologies in the intermodal transport area, *European Journal of Operational Research* 152, 410-419.
- Arnold, P., Peeters, D., and Thomas, I. (2004). Modelling a rail/road intermodal transportation system. *Transportation Research Part E*, 40, 255–270.
- Arnold, P. en Thomas, I. (1999). Localisation des centres de transbordement dans un système multi-reseaux: essai de formalisation. *L'espace géographique*, 3, 193-204.
- Ashayeri, J. and Rongen, J. (1997). Central distribution in Europe: a multi-criteria approach to location selection. *The International Journal of Logistics Management* 8, 97–109.
- Balakrishnan, A. and Graves, S.C. (1989). A composite algorithm for a concave-cost network flow problem. *Networks* 19, 175-202.
- Bontempi, G., Gambardella, L.,M., and Rizzoli, A.E. (2005). Simulation and Optimisation for Management of Intermodal Terminals. IDSIA, Istituto dalle Molle di Studi sull'Intelligenza Artificiale. Lugano, Switzerland.  
<http://www.idsia.ch/~luca/esm97.pdf> [Accessed: October 2005]
- Bortfeldt, A. and Gehring, H. (2001). A hybrid genetic algorithm for the container loading problem, *European Journal of Operational Research* 131, 143-161.
- Brans, J.P. and Mareschal, B. (1994). "The PROMCALC & GAIA decision support system for MCDA", *Decision Support Systems*, 12, pp. 297-310.
- Brans, J.P. (1982). 'L'ingénierie de la décision. Elaboration d'instruments d'aide à la décision. Méthode PROMETHEE", in *L'aide à la décision: Nature, instruments et perspectives d'avenir*, Nadeau, R. and Landry, M. Eds. (252p.), Presses de l'Université Laval, Québec, Canada, 183-214.
- Brooke, J. (2002). Stakeholder Participation in Port Development Decision Making: How?, Where? and When? Proceedings of the 30th International Navigation Congress (PIANC 2002), Sydney, Australia, 1990-1991.
- Bruzzone, A.G. and Signorile, R. (1996). Genetic algorithms and simulation as support for planning a port terminal. In: A.G. Bruzzone, J.H. Kerckhoffs (eds.), *Simulation in Industry*, 8th European Simulation Symposium, 1996. Genoa: Society for Computer Simulation International.
- Bryan, D.L. and O'Kelly, M.E. (1999). Hub-and-spoke networks in air transportation: an analytical review. *Journal of Regional Science* 39 (2), 275-295.
- Campbell, J.F. (1996). Hub location and the p-hub median problem. *Operations Research* 72, 387-405.
- Campbell, J.F. (1994). Integer programming formulations of discrete hub location problems. *European Journal of Operations Research* 72, 387-405.
- Crainic, T.G. (2000). Service network design in freight transportation. *European Journal of Operations Research* 122, 272-288.
- Declercq, E. and Verbeke, A. (1999). The EMOLITE project: Evaluation Model for the Optimal Location of Intermodal Terminals in Europe. *Studies in Locational Analysis: Managerial Methods in Location*, 13, June 1999, BEIF - Department of Management Informatics, Brussels, Belgium.
- Degano, C. and Pellegrino, A. (2002). Multi-Agent Coordination and Collaboration for Control and Optimization Strategies in an Intermodal Container Terminal. *IEEE International Engineering Management Conference*.
- Degano, C., Di Febbraro, A., and Fornara, P. (2001). Fault diagnosis in an intermodal container terminal. *8th IEEE International Conference on Emerging Technologies and Factory Automation*, 2, 433-440.
- Dong, J-W. and Li, Y-J. (2003). Agent-based design and organization of intermodal freight transportation systems. *Second International Conference on Machine Learning and Cybernetics*, 2269-2274.
- Ernst, A.T. and Krishnamoorthy, M. (1998). Exact and heuristic algorithms for the uncapacitated multiple allocation p-hub median problem. *European Journal of Operations Research* 104, 100-112.
- European Commission (1996). *Transport Research APAS, Cost-benefit and multi-criteria analysis for nodal centres for goods*, Office for Official Publications of the European Community, Luxembourg.
- Funk, P., Vierke, G., and Bürckert, H-J. (1999). A Multi-Agent Systems Perspective on Intermodal Transport Chains, *Logistik-Management-Tagung LMT-99*.
- Funk, P., Vierke, G., and Bürckert, H-J. (1998). A Multi-Agent Perspective on Intermodal Transport Chains. *Deutsches Forschungszentrum für Künstliche Intelligenz, Report DFKI-TM-98-06*. Saarbrücken, Germany, 1-14.
- Gambardella, L. M., Mastrolilli, M., Rizzoli, A. E., and Zaffalon, M. (2001). An optimization methodology for intermodal terminal management. *Journal of Intelligent Manufacturing*, 12 (5-6): 521-534.
- Gambardella, L.M., Bontempi, G., Taillard, E., Romanengo, D., Raso, G., and Piermari, P. (1996). Simulation and forecasting in intermodal container terminal. In: A.G. Bruzzone, J.H. Kerckhoffs (eds.), *Simulation in Industry*, 8th European Simulation Symposium, 1996. Genoa: Society for Computer Simulation International.
- Groothedde, B. and Tavasszy, L. A. (2000). Optimization of strategic multimodal freight transport networks using simulated annealing. *Proceeding of the EURO XVII: 17th European Conference on Operational Research*. Budapest, Hungary, July 16-19, 2000
- Guldmann, J.-M. and Shen, G. (1997). A general mixed-integer nonlinear optimization model for hub network design. Presented at the 44th North American meeting of the Regional Science Association International, Nov. 6-9, 1997, Buffalo, NY, USA.
- Hamacher, H.W. and Nickel, S. (1998). Classification of location models. *Location Science*, 6, 229-242.

- Hamacher, H.W., Labbe, M., Nickel, S., and Sonneborn, T. (2000). Polyhedral properties of the uncapacitated multiple allocation hub location problem. Institut fuer Techno- und Wirtschaftsmathematik (ITWM), Technical Report 20, 2000.
- Henesey, L. (2004a). Enhancing Container Terminal Performance: A Multi Agent Systems Approach, Lic. Thesis. Karlshamn, Sweden ISBN 91-7295-040-4.
- Henesey, L. (2004b). "A Multi Agent Based Simulator for Managing a Container Terminal" 2nd European Workshop on Multi-Agent Systems (EUMAS 2004), December 16 - 17, 2004, Barcelona, Spain.
- Henesey, L., Notteboom, T., and Davidsson, P. (2003a). "Agent-based simulation of stakeholders relations: An approach to sus-tainable port terminal management". International Association of Maritime Economists Annual Conference, Busan, Korea.
- Henesey, L., Wernstedt, F., and Davidsson, P. (2003b). Market-Driven Control in Container Terminal Management. 2nd International Conference on Computer Applications and Information Technology in the Maritime Industries.
- Henesey, L. (2002). Enhancing Terminal productivity through Artificial intelligence: Multi-Agent Approach, Proceedings of the 26th Terminal Operators Conference (TOC-2002), Antwerpen, Belgium.
- Higgins, A., Kozan, E. and Ferreira, L. (1996). Optimal Scheduling of Trains with Dynamic Priority/ Transportation Research. 30B, 147-161.
- Holmqvist, K., Migdalas, A., and Pardalos, P. (1998). GRASP algorithm for the single source uncapacitated minimum concave-cost network flow problem, DIMACS Series, 40. American Mathematical Society, Providence, RI, 131-142.
- Horst, R. and Tuy, H. (1996). Global Optimization (Deterministic Approaches). Springer-Verlag, Berlin.
- Kim, K.H. and Kim, K.Y. (1999). "Routing straddle carriers for the loading operation of containers using a beam search algorithm." Computers & Industrial Engineering 36, No. 1: 109-136.
- Klincewicz, J.G. (1996). A dual algorithm for the uncapacitated hub location problem. Location Science 4, 173-184.
- Klincewicz, J.G. (1991). Heuristics for the p-hub location problem. European Journal of Operational Research 53, 25-37.
- Kozan, E. (2000). Optimising container transfers at multimodal terminals, Mathematical and Computer Modelling 31, 235-243
- Kozan, E. and Preston, P. (1999). "Genetic algorithms to schedule container transfers at multimodal Terminals." International Transactions in Operational Research 6, 3, 311-329.
- Kozan, E. (1997). Increasing the operational efficiency of container terminals in Australia, Journal of the Operational Research Society 48(2), 151-161.
- Macharis, C. (2001). The Optimal Location of an Intermodal Terminal: A real world application. Proceeding of the Nectar Conference No. 6, European Strategies in the Globalising Markets, Transport Innovations, Competitiveness and Sustainability in the Information Age, 16-18 May 2001, Helsinki, Finland.
- Macharis, C.; Brans, J.P. en B. Mareschal (1998). "The GDSS Promethee procedure", Journal of Decision Systems, 7, 283-307.
- Maggi, E. (1998). "The Location of Logistics Nodes", in: Neptune Supporting Co-operation, Study on the Location of Logistics Nodes, ISTIEE, Trieste, 1-29.
- Mastrolilli, M.F.N., Gambardella, L.M., Rizzoli, A.E., and Zaffalon, M. (1998). Simulation for policy evaluation, planning and decision support in an intermodal container terminal. International Workshop on Modeling and Simulation within a Maritime Environment.
- Mazzucchelli, M., Recagno, V., and Sciotto, G. (1995). Evaluation of Interport Performances: A State Automaton Approach. Proceedings of the Vehicle Navigation and Information Systems Conference in Conjunction with the Pacific Rim TransTech Conference, 6th International VNIS, 'A Ride into the Future'. 30 July-2 Aug 1995, 272 - 279.
- McCalla, R., Slack, B., and Comtois, C. (2001). Intermodal Freight Terminals: Locality and Industrial Linkages. Canadian Geographer; Fall 2001; 45, 3, 404; Academic Research Library.
- Minoux, M. (1989). Network synthesis and optimum network design: models, solution methods and applications. Network 19, 313-360.
- Nickel S., Schoebel, A., and Sonneborn, T. (2000). Hub location problems in urban traffic networks. In: Niittymaki, Pursula (Eds.), Mathematical Methods and Optimization in Transportation Systems. Kluwer Academic Publishers, Dordrecht, 95-108.
- Nierat, P. (1997). Market area of rail-truck terminals: pertinence of the spatial theory. Transportation Research A 31, 109-127.
- Nierat, P. (1992). Transport combine rail-route: contraintes et performances des dessertes routi eres. In: Proceedings of the Sixth World Conference on Transport Research IV, 2733-2743.
- O'Kelly, M.E. and Bryan, D. (1998). Hub location with flow economies of scale. Transportation Research B 32 (8), 605-616.
- O'Kelly, M., Skorin-Kapov, D., and Skorin-Kapov, J. (1995). Lower bounds for the hub location problem. Management Science 41 (4), 713-721.
- O'Kelly, M.E. (1987). A quadratic integer program for the location of interacting hub facilities. European Journal of Operational Research 32, 393-404.
- Preston, P. and Kozan, E. (2001). "A Tabu Search Technique Applied to Scheduling Container Transfers", Transportation Planning and Technology. 24.2, 135-154.
- Proshun, S.-R. (2003) Container World: Global agent-based modelling of the container transport business. 4th International Workshop on Agent-Based Simulation, Montpellier, France.
- Queensland Transport (2005) SEQ Freight Intermodal Terminal Study: Stage 2 Additional Site Needs Investigation, Queensland Transport Rail Ports & Freight, May 2005.

- Racunica, I. and Wynter, L. (2005). Optimal Location of Intermodal Freight Hubs Transport Research Part B, 39, 453-477
- Rail Freight Group (2005). Rail Freight Online <http://www.railfreightonline.co.uk> [Accessed: September 2005]
- Rizzoli, A., Funk, P., and Gambardella, L. (2002). An architecture for agent based simulation of rail/road transport. International Workshop on Harbour, Maritime & Multimodal Logistics Modelling and Simulation.
- Rizzoli, A.E., Fornara, N., and Gambardella, L.M. (1999) A Simulation tool for combined rail/road transport in intermodal terminals, MODSIM 1999, Modelling and Simulation Society of Australia and New Zealand.
- Russell, S. J. and Norvig, P. (2003). Artificial Intelligence: A Modern Approach, Second Edition. Pearson Education International.
- Rutten, B.J.C.M. (1995). On medium distance intermodal rail transport, Delft, Phd-thesis.
- Sirikijpanichkul, A., and Ferreira, L. (2005). Quantifying Air Quality Impact: A Review of Literature. Queensland University of Technology, Brisbane. (Working Paper)
- Skorin-Kapov, D., Skorin-Kapov, J., O'Kelly, M. (1996). Tight linear programming relaxations of uncapacitated p-hub median problems. European Journal of Operations Research 94, 582-593.
- Skorin-Kapov, D. and Skorin-Kapov, J. (1994). On tabu search for the location of interacting hub facilities. European Journal of Operational Research 73 (3), 501-508.
- Slack, B. (1998). Intermodal transportation. In: Hoyle, B., Knowles, R. (Eds.), Modern Transport Geography. Wiley, Chichester.
- Slack, B., Comtois, C., and McCalla, R. (1997). 'Spatial Impacts of Transportation Terminals: Local Externalities and Economic Development' in Cricenti, M. and Varani, N. (eds.) Percorsi Geografici (1996-1997) (Genova: Associazione Italiana Insenanti di Geografia) 177-91
- Sohn, J. and Park, S. (2000). The single allocation problem in the interacting three-hub network. Networks 35 (1), 17-25.
- Strategic design + Development Pty Ltd (2004). Regional Intermodal Terminals – Indicators for Sustainability. Sea Freight Council of NSW Inc., Sydney.
- Taniguchi, E., Thompson, R.G., Yamada, T., and Duin, R.V. (2001). City Logistics: Network Modelling and Intelligent Transport Systems, Pergamon, Elsevier Science Ltd., Oxford, UK.
- Verter, V. and Dincer, M.C. (1995). Facility location and capacity acquisition: an integrated approach. Naval Research Logistics 42, 1141-1160.
- Visual Decision Inc. (1999). Decision Lab 2000 - Getting Started Guide, Montreal, Canada.
- West, N. and Kawamura, K. (2005). Location, Design and Operation of Future Intermodal Rail Yards: A Survey. Transport Research Board.
- Zhu, K. and Bos, A. (1999). Agent-based design of intermodal freight transportation systems, Proceedings of the NECTAR Conference, Delft University of Technology, Dept. of Transportation and Logistics' Organization. Delft, The Netherlands.