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# THE ECONOMIC EVALUATION OF INTERCITY INTERMODAL LOGISTICS

Cheng-Min FENG
Professor
Institute of Traffic and Transportation
National Chiao Tung University,
TAIWAN
Fax: 886-2-23494965
E-mail: cmfeng@mail.nctu.edu.tw

Hsin-Hsun HUANG
Ph.D. Student
Institute of Traffic and Transportation
National Chiao Tung University,
TAIWAN
Fax: 886-2-23494965
E-mail: lance@iot.gov.tw

**Abstract:** To find the maximum social welfare, this paper incorporates the external costs of transportation to propose an Intercity Intermodal Logistics strategy where the railroad system is responsible for long-distance line-haul transportation and logistics companies are responsible for regional pickup and distribution of commodities. A multi-objective mathematical model is thus established to determine the financial profits and economic benefits, location of rail logistics terminals, and dispatching freight routes. In addition, an economic evaluation is carried out through a comparison with Intercity Logistics Highway Transportation. Empirical analysis results show that Intercity Intermodal Logistics is economically feasible.

**Key Words**: intercity and city logistics, intermodal, economic evaluation, multi-objective programming, rail.

## 1. INTRODUCTION

Based on the scope of distribution, logistics can be divided into international logistics, intercity logistics, and city logistics. Intercity logistics relies mostly on door-to-door highway transportation. In the last decades, however, highway transportation have brought about adverse impacts such as traffic congestion, air pollution, noise, and high energy consumption, which have resulted in widespread public concern. In particular, its adverse environmental impact has become the focus of international attention. As a result, governments in the Netherlands, U.K., Japan, and Taiwan have included the development of sustainable transport systems into their mid and long-term transportation policies (Rutten, 1998; Woodburn, 2001). These governments have likewise explored alternative modes of transportation with lesser environmental impact, such as rail and coastal shipping, and have used intermodal transportation, such as the combination of rail and highway or the combination of costal shipping and highway, to replace highway transportation.

Taiwan has a small land area. Some intercity logistics companies often have difficulty finding locations for sorting and warehousing within a city. In addition, traffic congestion makes it difficult to control delivery time, thus affecting the companies' overall performance and service quality. On the other hand, Taiwan Rail Administration (TRA) enjoys advantage in service provision through its comprehensive island-wide transport network, right of way, and reliable schedules; TRA likewise has access to good locations and warehouse facilities within a city. Therefore, if TRA can cooperate with the aforementioned logistics companies and carefully plan and allocate the available resources, they can jointly help minimize urban congestion, solve the logistics companies' difficulty in finding terminal locations, and generate more profit opportunities for TRA.

In line with the policy for sustainable transportation and to create a win-win situation for both TRA and logistics companies, this study proposes an Intercity Intermodal Logistics strategy in which the railroad system is responsible for long-distance line-haul transportation and for the provision of Rail Logistics Terminal (RLT) in cities, while logistics companies are responsible for regional pickup and distribution of commodities. The economic viability of the Intercity Intermodal Logistics strategy will determine the willingness of companies to invest, the adjustment of tax and insurance system, and government's subsidy policy, which may become part of the market rules in the future. From the government's perspective of pursuing maximum social benefit, assessments of such economic viability are critical. Based on the above explanations, the main objective of this study is to assess the economic benefits of Intercity Intermodal Logistics, including its financial profits and external costs of transportation. The outline of the paper is as follows: Chapter 2 Problem Analysis, Chapter 3 Mathematical Model Development, Chapter 4 Empirical Analysis and Discussions, and Chapter 5 Conclusions and Recommendations for Future Research.

## 2. PROBLEM ANALYSIS

The Intercity Intermodal Logistics strategy proposed in this study is different from the current intercity logistics transport strategy-Intercity Logistics Highway Transportation, where cargo trucks running on the highways are used for intercity long-distance transport, while pickup and distribution trucks are used for local door-to-door pickup and delivery. To prevent tardiness and delays caused by other transportations, the intercity long-distance line-haul transportation is replaced by rail transport, which has right of way and reliable transportation schedules that enable customer to keep track of goods delivery. On the other hand, logistics companies can pick up and deliver goods using existing terminals, vehicles, information facilities, and convenient pickup points (such as convenient stores, drop-offs, or post offices) to receive customers' goods; pickup/delivery trucks are then used for pickup and delivery in pickup points or from customers. The RLTs are in turn used as transshipment points between pickup/delivery trucks and line-haul transport, and logistics companies can use the RLT internal facilities for warehousing and sorting. The above discussion implies that the Intercity Intermodal Logistics, which integrates the activities of movement, freight transportation, warehousing, sorting, information flow, is different from traditional freight transportation. Since this study emphasizes intercity transport, the study reasonably simplifies the pickup and delivery network connecting pickup points and customers in city logistics, and uses the centroid as the representative of widespread pickup points as shown in Figure 1.

The operation planning of Intercity Intermodal Logistics can be divided into three levels: (1) Long-term Strategic Planning, which refers to the planning of the size and location of terminals resulting from an increase or decrease in the demands of goods; (2) Tactical Planning, which refers to the adjustment of the fleet size due to an increase or decrease in the demand of goods; and (3) Operational Planning, which refers to the planning of o-d pair freight routing and scheduling. Since the efficiency of transshipment in the RLT is critical to the success of Intercity Intermodal Logistics and since location selection is the primary consideration in operation planning, this study uses the selection of RLT location as a decision variable in Strategic Planning.

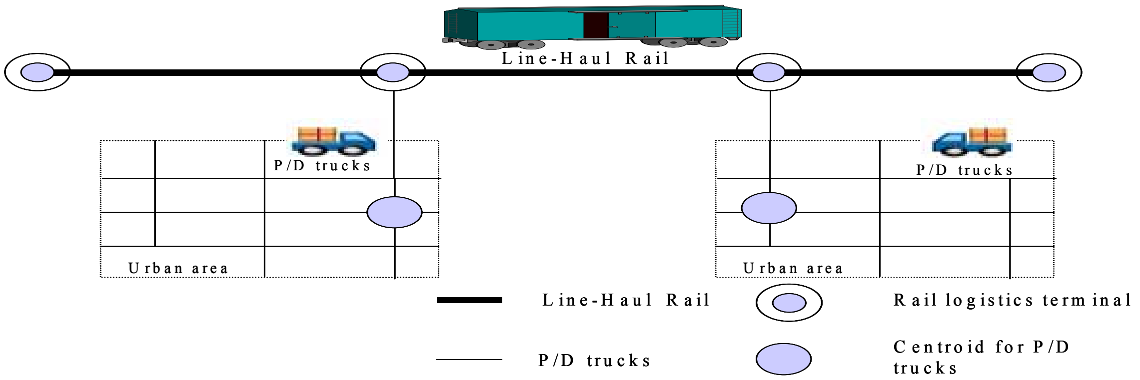


Figure 1. Intercity Intermodal Logistics Strategy

Whether the Intercity Intermodal Logistics is feasible involves the following issues:
1.Are there financial profits? What are its financial profits compared with Intercity Logistics Highway Transportation?
2.Are there economic benefits? What are its economic benefits compared with Intercity Logistics Highway Transportation?
To resolve the aforementioned issues, this study uses the multi-objective mathematical model of Intercity Intermodal Logistics to determine the financial profits and economic benefits, and select RLT locations. To evaluate the economic viability of the Intercity Intermodal Logistics, and considering part of the quantifiable economic benefits and costs have been involved in financial profits, this study uses the following definitions:

If $B_I \geqq B_H$, Plan I is economically viable;

If $B_I < B_H$, then Plan I is not economically viable;

where $B_I = \pi_I - EC_I$ = economic benefit of Intercity Intermodal Logistics;

$B_H = \pi_H - EC_H$ = economic benefit of Intercity Logistics Highway Transportation;

and $\pi_I$ = financial profit (benefit-cost) of Intercity Intermodal Logistics;

$\pi_H$ = financial profit (benefit-cost) of Intercity Logistics Highway Transportation;

$EC_I$ = external cost of Intercity Intermodal Logistics;

$EC_H$ = external cost of Intercity Logistics Highway Transportation.

In performing the economic assessment of Intercity Intermodal Logistics, the external costs of transportation must be included. Based on literature review (Mayeres *et al.*, 1996; Persson and Ödegaard, 1995), this study defines the external costs of transportation as follows: the cost of the adverse impacts caused on the society or the environment when people engage in transportation activities yet these costs are incurred or assumed by other parties because the doers themselves are either unaccountable or have failed to pay for these costs. The other parties referred to here may include neighbors, other countries and continents, the world, or the next generation.

Since the biggest difference between the Intercity Intermodal Logistics proposed in this study and highway transportation lies in intercity long-distance line-haul transportation, air pollution and accidents are primary considerations in examining the external costs incurred by rail and highway transportations; congestion and noise are not included in the scope of analysis of this study. In the assessment of the external costs of the different modes of transportation, the marginal social cost can better maximize resource allocation efficiency compared with average social cost. Since the marginal social cost is the sum of personal marginal resource cost and marginal external costs already paid for by the user, theoretically, the required social cost or external costs should be the marginal social cost or external costs incurred by society for every additional unit of transportation service. It should not be the average social costs or external costs. In practical, it is difficult to develop accurate estimates of the marginal social and external costs of freight transportation. For example, good data are available on the number of fatalities and personal injuries associated with freight rail operation nationally, enabling the average accident cost per ton-kilometer to be derived. However, the marginal accident cost of one additional ton-kilometer transported by freight rail is much more difficult to estimate. Since one is unable to accurately estimate the marginal costs of each unit of transportation (e.g., each ton-kilometer) in widely varying circumstance, two alternative choices are used. One is to ignore external costs and estimate user charges and taxes solely on the basis of public facility use or other services provided by the public sector; the other is to add some uniform charge to reflect external costs and accept a degree of cross-subsidization within each transportation mode. The analysis in this paper tends toward the second option and develops conservative estimate of average costs largely derived from aggregate data.

There are few papers to be found in the literature that directly address these issues. Nevertheless, references for the model construction process include: relevant literature on single-source capacitated facility location problem (SSCFLP) by Sridharan(1993), Klincewicz and Luss(1986), Beasley (1993), Holmberg *et al.*(1999), Rönnqvist *et al.*(1999), Pirkul and Jayaraman(1996), Taniguchi *et al.*(1999), Tragantalerngsak *et al.* (2000), and Klose (2000). Likewise, literature on hub location problem research includes those of O'Kelly (1987, 1992), Aykin (1995), Campbell (1994), Jaillet *et al.* (1996), and others. Additionally, literatures on hub network design problem include those of Kuby and Gray (1993), Kim *et al.* (1999).

Summarizing and reviewing the aforementioned literatures and comparing them against the issues that this research seeks to resolve, it is hence reasonable to propose a single-period, multicommodity, two-echelon capacitated facility location model that limits customer demand points and the provision of needed commodities to a single source. With reference to actual transport modes of the TRA and city logistics companies, the hub location and hub-and-spoke network models are also integrated to formulate a model of Intercity Intermodal Logistics. As such, this research explores in-depth the cooperation between TRA and city logistics companies to present the benefits of the business strategy on logistics service.

## 3. MODEL DEVELOPMENT

This chapter develops a multi-objective mathematical model based on Intercity Intermodal Logistics. The chapter is divided into model assumptions, development of the mathematical programming model, and external costs.

### 3.1 Model Assumptions

To develop the mathematical model in this study, some assumptions are given as follows:

1.Permitting TRA to cooperate with one or multiple logistics companies in the actual implementation of Intercity Intermodal Logistics.

2.The entire delivery process starting from customer pick-up points to customer receiving point is divided into two major parts. TRA is responsible for the long-distance line-haul transportation across cities, while city logistics companies are responsible for pickup/delivery within cities using small pickup/delivery trucks.

3.The RLT is composed of the loading/unloading area and sorting/temporary warehousing area (see figure 2). TRA is responsible for cargo loading and unloading, while the city logistics companies are responsible for moving commodities between the loading/unloading area and sorting/temporary warehousing area.

4.During the transshipment period, the RLT allows city logistics companies to perform simple sorting or short-term storage of commodities. This study, however, does not take inventory issues into consideration.

5.Given the capacity, the intermodal logistics operator would meet the capacity through the operation strategies.

6.Transshipment costs include the cost of loading the cargos at the departure RLT plus the cost of unloading at the arrival RLT. Sharing of the transshipment cost will be negotiated by TRA and logistics companies. In addition, as the market for time-sensitive delivery increases, promptness in delivery becomes more critical.

7.The origin/destination points of different commodity deliveries (O-D pairs) and number of deliveries are given.

8.The location of customers and their demands for the different kinds of commodities are given.

9.The various commodities needed by customers are supplied and delivered by a single RLT.

10.The cost of rail line-haul transport and the pickup/delivery cost at the origin centroid or destination centroid are given.

11.The capacity of rail transport routes and vehicles should fit in the Intercity Intermodal Logistics strategy.

12.The origin node or destination node is represented by the centroid. The planning on pickup/delivery networks, terminal locations, size of transportation fleet, and vehicle routing will not be the decision part of this study at present.

13.City logistics companies will independently plan for and install internal and external relevant facilities inside the sorting/temporary warehousing areas to fully comply with their own demands. The companies will shoulder the installation and operation costs. On the other hand, TRA will shoulder the improvement cost of facilities and logistics facilities inside the loading/unloading areas.

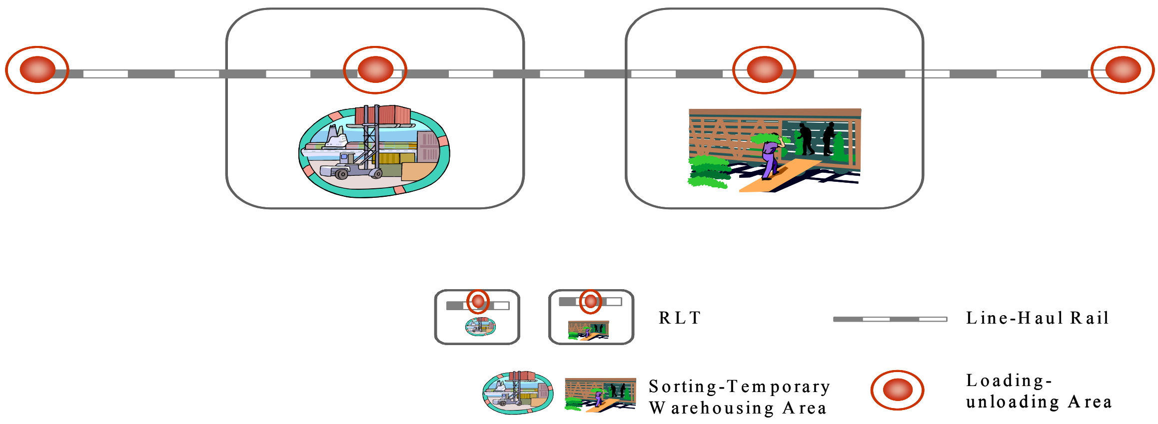


Figure 2. Rail Logistics Terminal (RLT)

### 3.2 Development of the Mathematical Programming Model

This study formulates a multi-objective mathematical model of the Intercity Intermodal Logistics based on the aforementioned model assumptions. In this model, TRA and logistics companies collaborate to operate Intercity Intermodal Logistics with the generation of maximum profit as their common objective. The most suitable RLT locations and freight routes are identified taking into account the RLT capacities and customer satisfaction.

The different parameters used in the model are as follows:

$I = \{1,2,......,n_i\}$ is a set of RLT candidate locations;

$K = \{1,2,......,n_k\}$ is a set of different kinds of commodity;

$O = \{1,2,......,n_o\}$ is a set of origin centroids;

$D = \{1,2,......,n_d\}$ is a set of destination centroids;

$P = \{1,2,......,n_p\}$ is a set of logistics companies;

$C^k_{oi,p}$ = the unit pickup/delivery cost of commodity $k$ from origin centroid $o$ to departure RLT $i$ for logistics company $p$ , $o \in O$ , $i \in I$ , $k \in K$ , $p \in P$;

$C^k_{ij}$ = the unit transport cost of commodity $k$ from departure RLT $i$ to arrival RLT $j$ , $i \neq j$ , $i, j \in I$ , $k \in K$;

$C^k_{jd,p}$ = the unit pickup/delivery cost of transporting commodity $k$ from arrival RLT $j$ to destination centroid $d$ for logistics company $p$ , $j \in I$ , $d \in D$ , $k \in K$ , $p \in P$;

$CT^k_{ij}$ = transshipment cost; includes cost of loading commodity $k$ from departure RLT $i$ to rail and the cost of unloading commodity $k$ from rail to arrival RLT $j$; where $i \neq j$ , $i, j \in I$ , $k \in K$;

$\alpha$ = represents the ratio of transshipment cost shared by TRA, and (1-$\alpha$)is the ratio of transshipment cost shared by the logistics companies; where $0 \leq \alpha \leq 1$ ;

$f_i$ = represents the installation costs of loading/unloading area in the departure/arrival RLT $i$ , $i \in I$ ;

$g_i$ = represents the installation costs of the sorting/temporary warehousing area in the departure/arrival RLT $i$ , $i \in I$ ;

$W^k_{od,p}$ = in the highway transportation mode initially used in the intercity logistics market, the volume of customer demand that logistics company $p$ transports commodity $k$ from source location $o$ to demand point $d$, and $o \in O$ , $d \in D$ , $k \in K$ , $p \in P$ ;

$\beta$ = the ratio of transfer in customer demands resulting from the shift of the initial highway transportation to intermodal transportation in the intercity logistics market, where $0 \leq \beta \leq 1$ (hereafter the Demand Transfer Ratio);

$A_i$ = the capacity limitation of the departure/arrival RLT $i$;

$a^k$ = the space occupied by commodity $k$ in RLT;

$TT^k_{oijd}$ = the total transport time needed to transport commodity $k$ from source location $o$ through departure RLT $i$ to arrival RLT $j$, and finally to demand point $d$ (including time required for transit and sorting at both departure RLT $i$ and arrival RLT $j$); where $o \in O$ , $i \neq j$ , $i, j \in I$ , $d \in D$ , $k \in K$ ;

$TM_{od}^{k}$ = represents time limit imposed by customer for transporting commodity $k$ from source location $o$ to demand point $d$; where $o \in O$ , $d \in D$ , $k \in K$ ;

$FT_{od}^{k}$ = the earnings of transporting commodity $k$ from origin centroid $o$ to destination centroid $d$ by rail;

$FF_{od}^{k}$ = the earnings of delivering commodity $k$ from origin centroid $o$ to destination centroid $d$ on the road;

$PL_i$ = the earnings from land rentals of RLT $i$.

The notation represented by different decision variables are explained below:

$y_i$ = 1 if the departure/arrival RLT is located at candidate location $i$;

$y_i$ = 0 otherwise, where $i \in I$.

$X_{oijd,p}^{k}$ = 1 represents logistics company $p$ transporting commodity k from source location $o$ to RLT $i$, and using the rail for transport to the arrival RLT $j$, and finally to demand point $d$;

$X_{oijd,p}^{k}$ = 0 otherwise, where $o \in O$, $i, j \in I$, $d \in D$, $k \in K$, $p \in P$.

According to the assumptions described in Section 3.1, the model can be formulated as follows:

$$\begin{aligned}\text{Max } Z_0 = &\sum_p \sum_o \sum_i \sum_j \sum_d \sum_k FT_{od}^{k} \beta W_{od,p}^{k} X_{oijd,p}^{k} + \sum_i PL_i y_i \\ &- \sum_p \sum_o \sum_i \sum_j \sum_d \sum_k C_{ij}^{k} \beta W_{od,p}^{k} X_{oijd,p}^{k} \\ &- \alpha (\sum_p \sum_o \sum_i \sum_j \sum_d \sum_k CT_{ij}^{k} \beta W_{od,p}^{k} X_{oijd,p}^{k}) - \sum_i f_i y_i \end{aligned} \tag{1}$$

$$\begin{aligned}\text{Max } Z_1 = &\sum_o \sum_i \sum_j \sum_d \sum_k (FF_{od}^{k} \beta W_{od,1}^{k} X_{oijd,1}^{k}) \\ &- \sum_o \sum_i \sum_j \sum_d \sum_k (C_{oi,1}^{k} \beta W_{od,1}^{k} X_{oijd,1}^{k} + C_{jd,1}^{k} \beta W_{od,1}^{k} X_{oijd,1}^{k}) \\ &- (1-\alpha)/p(\sum_o \sum_i \sum_j \sum_d \sum_k CT_{ij}^{k} \beta W_{od,1}^{k} X_{oijd,1}^{k}) - \sum_i g_i y_i - \sum_i PL_i y_i \end{aligned} \tag{2}$$

$$\vdots$$

$$\begin{aligned}\text{Max } Z_p = &\sum_o \sum_i \sum_j \sum_d \sum_k (FF_{od}^{k} \beta W_{od,p}^{k} X_{oijd,p}^{k}) \\ &- \sum_o \sum_i \sum_j \sum_d \sum_k (C_{oi,p}^{k} \beta W_{od,p}^{k} X_{oijd,p}^{k} + C_{jd,p}^{k} \beta W_{od,p}^{k} X_{oijd,p}^{k}) \\ &- (1-\alpha)/p(\sum_o \sum_i \sum_j \sum_d \sum_k CT_{ij}^{k} \beta W_{od,p}^{k} X_{oijd,p}^{k}) - \sum_i g_i y_i - \sum_i PL_i y_i \end{aligned} \tag{3}$$

Subject to

$$\sum_p \sum_o \sum_j \sum_d \sum_k a^k \beta W_{od,p}^{k} (X_{oijd,p}^{k} + X_{ojid,p}^{k}) \leq A_i y_i \quad \forall i \in I \tag{4}$$

$$\sum_i \sum_j X_{oijd,p}^{k} = 1 \quad \forall o \in O, \forall d \in D, \forall k \in K, \forall p \in P \tag{5}$$

$$\sum_p \sum_o \sum_d \sum_k X_{oijd,p}^{k} = 0 \quad \forall i = j \in I \tag{6}$$

$$X_{oijd,p}^{k} \leq y_i \quad \forall o \in O, \forall i, j \in I, \forall d \in D, \forall k \in K, \forall p \in P \tag{7}$$

$$X^k_{oijd,p} \le y_j \quad \forall o \in O, \forall i, j \in I, \forall d \in D, \forall k \in K, \forall p \in P \tag{8}$$

$$X^k_{oijd,p} = \{0,1\} \quad \forall o \in O, \forall i, j \in I, \forall d \in D, \forall k \in K, \forall p \in P \tag{9}$$

$$y_i = \{0,1\} \quad \forall i \in I \tag{10}$$

Likewise, formulas (1), (2), and (3) can be changed to general formula as follows:

$$\begin{aligned} \text{Max } Z_0 = & \sum_p \sum_o \sum_i \sum_j \sum_d \sum_k FT^k_{od} \beta W^k_{od,p} X^k_{oijd,p} + \sum_i PL_i y_i \\ & - \sum_p \sum_o \sum_i \sum_j \sum_d \sum_k C^k_{ij} \beta W^k_{od,p} X^k_{oijd,p} \\ & - \alpha (\sum_p \sum_o \sum_i \sum_j \sum_d \sum_k CT^k_{ij} \beta W^k_{od,p} X^k_{oijd,p}) - \sum_i f_i y_i \end{aligned} \tag{11}$$

$$\begin{aligned} \text{Max } Z_r = & \sum_o \sum_i \sum_j \sum_d \sum_k (FF^k_{od} \beta W^k_{od,r} X^k_{oijd,r}) \\ & - \sum_o \sum_i \sum_j \sum_d \sum_k (C^k_{oi,r} \beta W^k_{od,r} X^k_{oijd,r} + C^k_{jd,r} \beta W^k_{od,r} X^k_{oijd,r}) \\ & - (1-\alpha)/p (\sum_o \sum_i \sum_j \sum_d \sum_k CT^k_{ij} \beta W^k_{od,r} X^k_{oijd,r}) - \sum_i g_i y_i - \sum_i PL_i y_i \\ & r = 1,2,\ldots,p \end{aligned} \tag{12}$$

The main objective of TRA that collaborates with logistics companies to implement the Intercity Intermodal Logistics is to generate maximum profit. The mathematical model is indicated in equation (11).

The two earnings include $\sum_p \sum_o \sum_i \sum_j \sum_d \sum_k FT^k_{od} \beta W^k_{od,p} X^k_{oijd,p}$ and $\sum_i PL_i y_i$ . $\beta W^k_{od,p}$ represents the volume of customer demand within the intercity logistics market, where highway transportation was initially used and was subsequently changed to intermodal transportation, and where logistics company $p$ transports commodity $k$ from source location $o$ to demand point $d$. The Demand Transfer Ratio $\beta$ is between 0 and 1. When $\beta$=1, it indicates that highway transportation had been used within the intercity logistics market, and that transport of commodity $k$ from source location $o$ to demand point $d$ by logistics companies $p$ in intercity logistics market has been changed to intermodal transport. When $\beta$ =0, it indicates that highway transportation was retained and none of the customer demands was changed to intermodal transport. When 0<$\beta$<1, it indicates that of the customer demands initially served through highway transportation, a $\beta$ ratio was changed to intermodal transport due to factors such as the special needs and preference of logistics companies, as well as the need for flexibility between road and intermodal transportation services.

Since the $\alpha$ is between 0 and 1, when $\alpha$=1, it indicates that the total transshipment costs incurred in transporting commodity $k$ from source location $o$ through departure RLT $i$ to arrival RLT $j$, and finally to demand point $d$, are born by TRA in whole. When $\alpha$=0, the total transshipment costs are born by the logistics companies. When 0<$\alpha$<1, it indicates that TRA and logistics companies each shares a percentage of the transshipment cost in accordance with the agreement entered into by the parties.

For the logistics companies, the objective of strategic cooperation with TRA and the joint use of the intermodal logistics is to generate maximum profit. The formula is indicated in equation (12).

$\sum_o \sum_i \sum_j \sum_d \sum_k (FF_{od}^k \beta W_{od,r}^k X_{oijd,r}^k)$ represents the income of the logistics company $r$ in transporting commodity $k$ from source location $o$ to departure RLT $i$ and from arrival RLT $j$ ( $\forall\ i \neq j$ , $i, j \in I$ ) to demand point $d$. The costs, i.e. financial costs, include $\sum_o \sum_i \sum_j \sum_d \sum_k (C_{oi,r}^k \beta W_{od,r}^k X_{oijd,r}^k + C_{jd,r}^k \beta W_{od,r}^k X_{oijd,r}^k)$ ,
$(1-\alpha)/p(\sum_o \sum_i \sum_j \sum_d \sum_k CT_{ij}^k \beta W_{od,r}^k X_{oijd,r}^k)$, $\sum_i g_i y_i$ , and $\sum_i PL_i y_i$ .

Constrain set (4) represents the capacity restriction of RLT $i$. Constrain set (5) ensures commodity $k$ from origin centroid $o$ is delivered to a single departure RLT $i$, and needed by destination centroid $d$ is delivered by a single arrival RLT $j$ only. Constrain set (6) describes the intercity line-haul transportation between RLTs must exist, and that delivery for the entire route is not made by pickup/delivery trucks. Constrain set (7) and (8) limit that RLT must first be located before items may be transported from origin centroid $o$ to departure RLT $i$ and delivered from arrival RLT $j$ to the destination centroid $d$. When time-sensitive commodity $k$ is needed, the following constrain must be added:

$$TT_{oijd}^k X_{oijd,p}^k \leq TM_{od}^k \quad \forall o \in O, \forall i, j \in I, \forall d \in D, \forall k \in K, \forall p \in P \tag{13}$$

Constrain set (13) ensures that the total operational time from origin centroid $o$ to destination centroid $d$ must satisfy customers' request.

### 3.3 External Costs

This study further took into account the external costs incurred in the commodity transport, such as air pollution and accidents, from the social cost perspective. The external costs were incorporated into the total cost of Intercity Intermodal Logistics to determine the economic benefits.

1.Air Pollution

Transport accounts for substantial fractions of direct emissions (i.e., "inventories") of three primary pollutants: volatile organic compounds (VOC), carbon monoxide (CO) and nitrogen oxides ($NO_x$) (Small and Kazimi, 1995). The reaction between VOCs and $NO_x$ results in secondary carbon, which is a primary component of particulate matters (PM). In addition, motor vehicles, especially those use diesel fuel, emit some particulate matters directly and also emit sulphur oxides ($SO_X$), primarily sulphur dioxide ($SO_2$). In recent years, the impacts of vehicle emissions have expanded to greenhouse gases, which are primarily carbon dioxide ($CO_2$). Based on the above, this study uses the effects of pollutants such as NOx, VOC, CO, SOx, $CO_2$, and particulate matters with diameter smaller than 10 $\mu$m (PM10) on health as basis for cost calculation. The external costs of air pollution can be calculated using formula (14):

$$ECE_{od} = EF_v^e \times \eta_v^e \times VKT_{od,v}^e \tag{14}$$

Where

$ECE_{od}$ = external costs of air pollution from $o$ to $d$ (NT$/unit time)

$EF_v^e$ = emission factor of air pollution $e$ caused by vehicle type $v$ (g/km)

$VKT^{e}_{od,v}$ = vehicle kilometer of vehicle $v$ that causes air pollution $e$ (km/unit time)

$\eta^{e}_{v}$ = unit cost of air pollution of vehicle $v$ that causes air pollution $e$ (NT\$/g)

$v$ = vehicle type ( $v1$: train, $v2$: light-duty diesel truck, $v3$: heavy-duty diesel truck)

$e$ =type of air pollution(NOx, VOC, CO, SOx, $CO_2$, PM10)

2.Accidents

The external costs of accidents of the unit transport service are uncompensated extra costs incurred during death, injuries, and financial damages due to accidents. The external costs of accidents can be calculated using formula (15):

$$ECA_{od} = r^{s}_{v} \times \theta^{s}_{v} \times VKT^{s}_{od,v} \tag{15}$$

Where

$ECA_{od}$ = external costs of accidents from $o$ to $d$ (NT\$/unit time)

$r^{s}_{v}$ = risk of accident of vehicle $v$ with severity $s$ (number of accidents/km)

$VKT^{s}_{od,v}$ = vehicle kilometer of vehicle v with severity $s$ (km/unit time)

$\theta^{s}_{v}$ = costs of accidents of vehicle $v$ with severity $s$ (NT\$/accident)

$v$ = vehicle type (train, light-duty diesel truck, heavy-duty diesel truck)

$s$ = severity of accident (fatal, injury)

Formulas (16) and (17) are derived as shown by incorporating the above external costs into the total cost of Intercity Intermodal Logistics. The total cost is the economical cost namely. Constrains used in the formulas are similar to those in formulas (4) to (10).

$$\begin{aligned}
\text{Max } Z^{*}_{0} = & \sum_{p}\sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k} FT^{k}_{od}\beta W^{k}_{od,r} X^{k}_{oijd,p} + \sum_{i} PL_{i} y_{i} \\
& - \sum_{p}\sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k} C^{k}_{ij}\beta W^{k}_{od,r} X^{k}_{oijd,p} \\
& - \alpha\Big(\sum_{p}\sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k} CT^{k}_{ij}\beta W^{k}_{od,r} X^{k}_{oijd,p}\Big) - \sum_{i} f_{i} y_{i} \\
& - \sum_{p}\sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k}\sum_{e} (EF^{e}_{v1} \times \eta^{e}_{v1} \times VKT^{e}_{ij,v1}) X^{k}_{oijd,p} \\
& - \sum_{p}\sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k}\sum_{s} (r^{s}_{v1} \times \theta^{s}_{v1} \times VKT^{s}_{ij,v1}) X^{k}_{oijd,p}
\end{aligned} \tag{16}$$

$$\begin{aligned}
\text{Max } Z^{*}_{r} = & \sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k} (FF^{k}_{od}\beta W^{k}_{od,r} X^{k}_{oijd,r}) \\
& - \sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k} (C^{k}_{oi,r}\beta W^{k}_{od,r} X^{k}_{oijd,r} + C^{k}_{jd,r}\beta W^{k}_{od,r} X^{k}_{oijd,r}) \\
& - (1-\alpha)/p\Big(\sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k} CT^{k}_{ij}\beta W^{k}_{od,r} X^{k}_{oijd,r}\Big) - \sum_{i} g_{i} y_{i} - \sum_{i} PL_{i} y_{i} \\
& - \sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k}\sum_{e} \Big(EF^{e}_{v2} \times \eta^{e}_{v2} \times (VKT^{e}_{oi,v2} + VKT^{e}_{jd,v2})\Big) X^{k}_{oijd,r} \\
& - \sum_{o}\sum_{i}\sum_{j}\sum_{d}\sum_{k}\sum_{s} \Big(r^{s}_{v2} \times \theta^{s}_{v2} \times (VKT^{s}_{oi,v2} + VKT^{s}_{jd,v2})\Big) X^{k}_{oijd,r} \\
& r = 1,2,\ldots,p
\end{aligned} \tag{17}$$

## 4. EMPIRICAL STUDY AND DISCUSSION

To test the feasibility and performance of the model developed in Section 3.2, this study used TRA, the only rail transport operator in Taiwan, as the railroad company that is responsible for long-distance rail line-haul transportation, and third-party logistics or feeder transport companies and intercity logistics distributors as logistics companies responsible for local pickup and distribution. In addition, the actual operating railroad network of TRA and the cities along TRA's routes were used in the empirical study to determine the financial profits and economic benefits of Intercity Intermodal Logistics, as well as the selection of RLT locations and freight routes for commodity transport. Economic viability is determined through a comparison between the economic benefits of Intercity Intermodal Logistics and Intercity Logistics Highway Transportation.

This study used established guidelines (Feng and Huang, 2003) to select 16 TRA terminals in Keelung, Shulin, Taoyuan, Chungli, Hsinchu, Chunan, Taichung, Yuanlin, Tounan, Chiayi, Tainan, Kaohsiung, Pintung, Ilan, Hualien, and Taitung as candidate RLT locations. Administrative areas were used as boundaries to establish eight source and demand points, namely: Keelung-Taoyuan district, Hsinchu-Miaoli district, Taichung-Changhwa district, Yunlin-Chiayi-Tainan district, Kaohsiung-Pintung district, Ilan district, Hualien district, and Taitung district. In addition, Taipei, Hsinchu, Taichung, Tainan, Kaohsiung, Ilan, Hualien, and Taitung were centroids of the above districts, respectively, as indicated in Figure 3. The commodities transported were small, lightweight, and higher-priced express documents, parcels, and time-sensitive commodities. Since unable to obtain information on the market size of the express delivery industry in Taiwan, this study used the actual business volume in transporting documents, samples, parcels, and other time-sensitive commodities in 2003 of a large Taiwan-based company (Logistics Company A) that was engaged in highway transportation and intercity logistics. The parameters used in the model were actual TRA operational data and Logistics Company A. Empirical tests were performed for "cooperation between TRA and a logistics company" and for an instance where "TRA alone bore all transshipment costs" (the Base Year Assumptions). Calculations of external costs were as follows:

1.Air Pollution

The emission factors for CO, NOx, and VOC were calculated by entering the relevant domestic raw data into the Mobile-Taiwan 2.0 software (1996), which was modified from the U.S. Mobile 5a. The emission factors for PM10 and SOx were calculated by substituting the relevant domestic raw data into U.S.AP-42. The emission factor for $CO_2$ was calculated based on the research result of Inge Mayeres *et al.* (1996). In addition, the *highway travel time survey* (2002) showed that the average traveling speed in urban areas in Taiwan was 40 kph while the intercity traveling speed was 90 kph. Thus the emission factors used in the test were those for the two speeds. On the other hand, the unit cost of city and intercity pollutants were calculated based on the research result of Inge Mayeres *et al.* (1996) and Fokenbrock, D.J. (1999). The kilometer distance from source to destination was calculated using *The Third Taiwan Area Integrated Transportation Systems Planning Study* (1999).

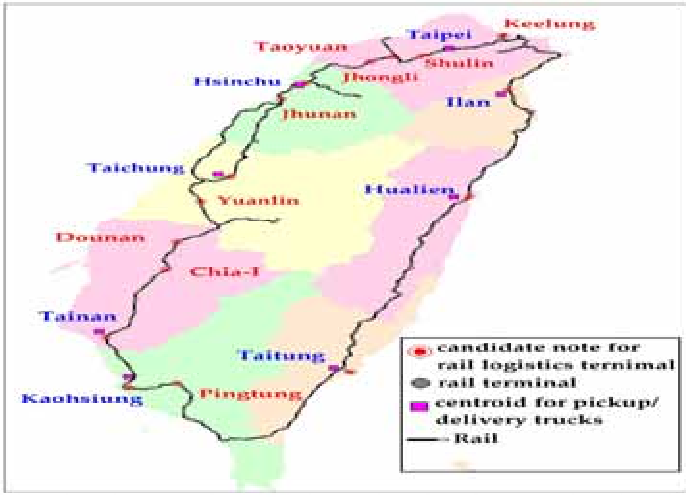


Figure 3. The Coverage of the Empirical Study and Candidate RLT Locations

2.Accidents

Due to limited data, the value for accident risk was calculated by: (number of accidents/number of moving vehicles)×(1/(travel distance in kilometers / unit time per vehicle)). The (number of accidents/number of moving vehicles) was calculated from the *Statistical Abstract of Transportation and Communication* (2003), while the (1/(travel distance in kilometers / unit time per vehicle)) was calculated from data of actual operations of Logistics Company A. Accident cost was calculated using the Chen and Su (2003) model for estimating cost of those fatal and injury casualties in road accidents. The kilometer distance from source to destination was calculated using *The Third Taiwan Area Integrated Transportation Systems Planning Study*.

This study used the weighting method to find solutions for the established multi-objective mathematical model. Lingo 7.0 and Excel were used in the computations. By manipulating the weights, a set of non-inferior solutions was calculated, as shown in Figure 4.

The total benefits ($Z=Z_0+Z_1$) corresponding to the different weights are indicated in Table 4. Table 4 shows that from the government's perspective, cooperation between TRA and logistics companies generated total daily benefit ranging from NT$1,667,576 to

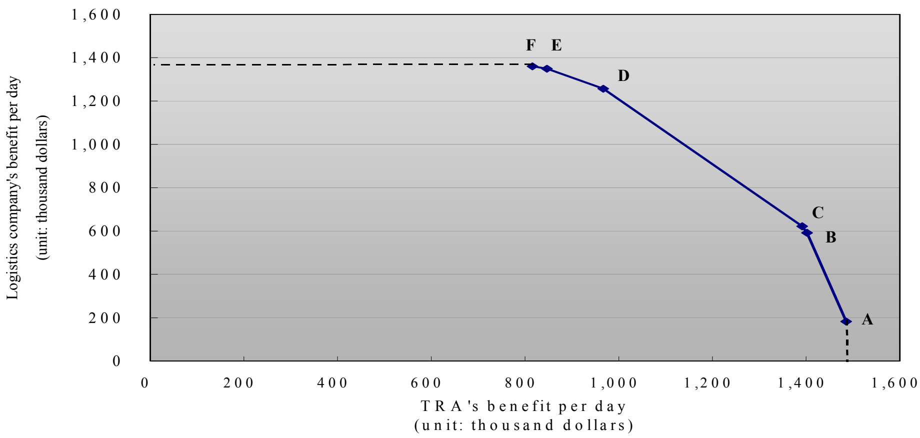


Figure 4. Non-inferior Solutions Set

NT$2,224,103. TRA alone generated total daily benefit ($Z_0$) ranging from NT$816,061 to NT$1,485,557, while logistics companies generated total daily benefit ($Z_1$) ranging from NT$182,019 to NT$1,359,964. Evidently, it would be economically viable for the government, TRA, and logistics companies to promote Intercity Intermodal Logistics.

Since the different weight combinations in the Weighting Method represents the different preferences of decision makers, it is necessary for the decision makers to treat fairly the parties collaborating in the Intercity Intermodal Logistics, i.e., by assigning the same weights to TRA and the logistics companies to improve the feasibility of promoting the strategy. Using the same weights, the calculated results were as follows: Eight terminals,namely those in Shulin, Hsinchu, Taichung, Tainan, Kaohsiung, Ilan, Hualien, and Taitung, were selected from the 16 candidate RLT locations. Five RLTs were in Taiwan's west corridor and three in Taiwan's east corridor. Through freight routes dispatching, it was found that transportation cost was lower when the shortest routes from the source point to departure RLT and from the arrival RLT to demand point were selected for transport; the route selected was able to satisfy the customer's demand for time-sensitive delivery. In addition, the pickup/distribution routes for demands in the different locations were limited to routes from the centroids to the nearest departure/arrival RLT. No distribution was made to nearby RLTs. These showed that the capacity of the eight selected RLTs was enough to serve customer demands during the Base Year.

Table 4. Different Weighted Non-inferior Solutions and Total Benefits

| Point | Weighting | | Non-inferior Solutions (NT$/day) | | Total Benefits (NT$/day) |
|---|---|---|---|---|---|
| | $W_1$ | $W_2$ | $Z_0$ | $Z_1$ | $Z=Z_0+Z_1$ |
| A | 1 | 0 | 1,485,557 | 182,019 | 1,667,576 |
| B | 0.9 | 0.1 | 1,401,996 | 591,516 | 1,993,512 |
| C | 0.8 | 0.2 | 1,391,548 | 621,721 | 2,013,269 |
| D | 0.5 | 0.5 | 967,049 | 1,257,054 | 2,224,103* |
| E | 0.2 | 0.8 | 846,964 | 1,349,388 | 2,196,352 |
| F | 0 | 1 | 816,061 | 1,359,964 | 2,176,025 |

Note: * represents the total economic benefits of Intercity Intermodal Logistics. Given that TRA and logistics companies have the same weights, the total daily financial profit would be NT$2,821,154 in Intercity Intermodal Logistics.

This study likewise used the aforementioned Logistics Company A to calculate the economic benefits of Intercity Logistics Highway Transportation, and make follow-up comparison with Intercity Intermodal Logistics. After entering the data in actual demands and operation for the year 2003 into formulas (18) and (19), the financial profits and economic benefits of Intercity Logistics Highway Transportation were calculated to be NT$2,842,811 per day and NT$2,114,666 per day, respectively.

$$\pi_H = \sum_o \sum_d \sum_k FF_{od}^k W_{od}^k - \left\{ \sum_o \sum_d \sum_k C_{od}^k W_{od}^k + \sum_i g_i \right\} \tag{18}$$

$$B_H = \sum_o \sum_d \sum_k FF_{od}^k W_{od}^k - \left\{ \sum_o \sum_d \sum_k C_{od}^k W_{od}^k + \sum_i g_i \right\} - (ECE_{od} + ECA_{od}) \tag{19}$$

Where $C_{od}^k$ = unit transport cost in transporting commodity k from source location *o* to demand point *d*;

$W_{od}^k$ = volume of customer demand for transporting commodity k from source location *o* to demand point *d*.

Definitions of all other parameters are the same as those in Section 3.2.

Based on the above calculations, the financial profits and economic benefits of Intercity

Intermodal Logistics and Intercity Logistics Highway Transportation are shown in Table 5. In the table, $\pi_I < \pi_H$. This means that, from a purely financial perspective, logistics companies are less willing to collaborate with TRA and invest in Intercity Intermodal Logistics. In the table, $B_I > B_H$. Based on the definition of economic feasibility in Chapter 2, this shows that the benefit of Intercity Intermodal Logistics is higher than that of Intercity Logistics Highway Transportation; therefore, the former is economically feasible. In summary, it is feasible and necessary to promote Intercity Intermodal Logistics to achieve the greatest overall social benefit. Through tax and insurance system adjustments, the government can internalize external costs such as air pollution and accidents, and reasonably reflect the actual costs of the different modes of transportation. Furthermore, the government can likewise use tax reduction or exemption and subsidies to encourage logistics companies to cooperate with TRA in the promotion of Intercity Intermodal Logistics.

Table 5. Comparison of the Financial Profits and Economic Benefits of Intercity Intermodal Logistics (I) and Intercity Logistics Highway Transportation (H)

Unit: NT$/day

| Strategy | Financial Profits ($\pi$) | External Costs ($EC$) | Economic Benefits ($B$) | $\pi_I - \pi_H$ | $B_I - B_H$ |
|---|---|---|---|---|---|
| I | 2,821,153 | 597,050 | 2,224,103 | -21,658 | 109,437 |
| H | 2,842,811 | 728,145 | 2,114,666 | | |

## 5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE STUDY

In pursuit of maximum social benefit, this paper includes external costs incurred in the commodity transport, such as air pollution and accidents, in addition to financial costs, into the total costs of Intercity Intermodal Logistics. This paper proposes a multi-objective mathematical model to establish an Intercity Intermodal Logistics model where the railroad system is responsible for long-distance line-haul transportation, while logistics companies are responsible for regional pickup and distribution of commodities. Empirical analysis shows that Taiwan has eight terminals that are suitable for use as RLTs. Since the Intercity Intermodal Logistics has a higher economic benefit compared with that of Intercity Logistics Highway Transportation, Intercity Intermodal Logistics is economically feasible. For this reason, the government needs to adjust the taxation and insurance systems and use tax reduction and exemption or subsidies to encourage rail and logistics companies to collaborate and promote Intercity Intermodal Logistics.

Since the scope of this study is focused on intercity logistics, it excluded issues on city logistics such as local pickup/distribution network, terminal location, size of freight team, and scheduling. Subsequent researches can consider these issues to establish a “city logistics” model, which can be integrated with this study to expand the scope of application of the entire model. Although the model established by this study is applicable for multi-commodities, it is limited by difficulties in data collection. Consequently, this study is limited at present to single commodities such as documents, samples, parcels, and other time-sensitive commodities. Subsequent studies can find ways to overcome the problem on data collection and explore the types of commodities best suited for Intercity Intermodal Logistics.

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