THE FLEET PLANNING FOR MULTI-MODAL EXPRESS SERVICES IN TAIWAN[1]

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Abstract: The time definite freight delivery carriers in Taiwan provide both air and ground express services for customers' time sensitive freight. The fleet planning problem for multi-modal express services must determine the most appropriate integrated fleet size and routes to minimize the total cost while meeting the service commitment of the air and ground express demands. This problem is formulated as an integer program in this study. A complete enumeration algorithm embedded with a degree and time constrained minimum spanning tree subproblem is developed for the problem. The largest express delivery carrier in Taiwan is utilized for numerical testing. Operating an integrated fleet instead of two separate fleets for each of two services is shown to result in savings of between 10-20%. Some future research recommendations are also made in the conclusion.

1. INTRODUCTION

Time definite common carriers in Taiwan are less-than-truck-load (LTL) common carriers. They offer a time guaranteed of delivery (next-day for instance) on all shipments. Taiwan is a small island geographically, a rectangular in shape, with an east-west distance of less than 150 kilometers and a north-south span less than 400 kilometers. The population and all major activities are highly concentrated on the west coast. There is currently only one National Highway System that fully connects all major cities on the west coast; although a second is under construction. Taiwan's major cities are, in sequence from the north to the south, Keelung, Taipei, Taoryuan, Jonglih, Shinchu, Taichung, Jiayih, Shinying, Tainan, Kaohsiung and Pingtong (see Figure 1). Taipei, Kaohsiung and Taichung are the largest three cities in Taiwan. They are located in the north, south and central parts of Taiwan respectively. It takes less than 5 non-stop driving hours by car to travel between Taipei and Kaohsiung if there is no major congestion. Due to the small distances, the time definite common carriers typically provide *next-day ground service* for locations on the island except for a few remote areas on the west coast, and areas between east and west coasts where two days are required.

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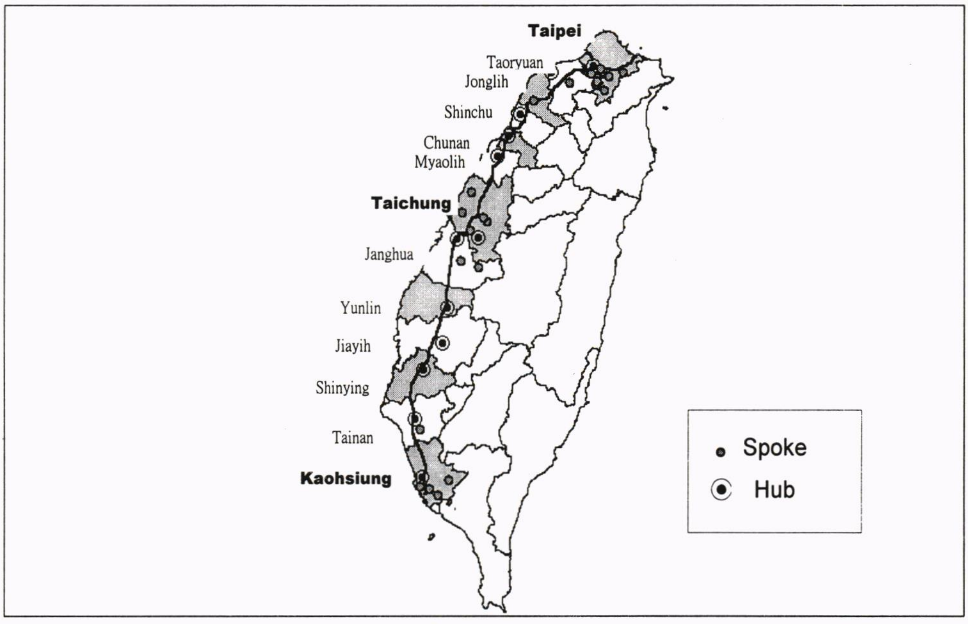

Figure 1: The line-haul operations of the ground-only express network in Taiwan

There is a growing demand for express services in Taiwan since the early 1980s. While the ground volume has only increased by approximately 10% (Table 1), the air volume in tonnage has more than doubled from 1991 to 1997 (Table 2).

Table 1: Freight Traffic of Private Trucking Companies

Year	Freight Tonnage		Ton-Kilometers		Average Freight Distance(KM)
	('000)	Index	('000)	Index	
1991(base year)	254,297	100	11,813,756	100	46.46
1992	267,955	105	12,219,892	103	45.60
1993	301,669	119	12,866,835	109	42.65
1994	313,436	123	13,091,360	111	41.77
1995	292,017	115	12,491,503	106	42.78
1996	289,446	114	11,990,977	102	41.43
1997	276,981	109	12,165,071	103	43.92

Source: Statistical Abstract of Transportation and Communications, 1998

There are many new entrants into the *same-day ground express service* while more and more existing next-day ground time definite carriers are also introducing the service as a result of this heightened demand. *Same-day ground express service* via tractor-trailers guarantees delivery on the same day of pickups, except when they arrive at their destinations after the office hours. Consignees may still be allowed to pickup their packages in person or have them delivered on the next day.

Since same-day ground express service requires slightly more than 8 service hours for the Taipei-Kaohsiung market, some new entrants into the field offer *same-day air express service* instead. The same-day air service cuts the service time in half to four hours. Most existing next-day ground time definite common carriers are planning to gradually enter the same-day air express market in order to remain competitive. Companies that provide both ground and air express services are termed as *multi-modal express services*. Since running both operations side by side without sharing any resources is a costly waste of resources, carriers should develop a cost effective integrated operation.

Table 2: Freight Traffic of Civil Aviation in Taiwan

Year	Freight Tonnage		Ton-Kilometers	
	('000)	Index(%)	('000)	Index(%)
1991(base year)	44,680	100	5,811	100
1992	53,129	119	7,060	121
1993	60,615	136	8,154	140
1994	70,819	159	9,504	164
1995	85,898	192	12,598	217
1996	94,398	211	14,372	247
1997	103,651	232	16,249	280

Source: Statistical Abstract of Transportation and Communications, 1998

The fleet planning problem for multi-modal express services is how to determine the size of an integrated vehicle fleet and their routes to simultaneously serve both same-day air and ground express markets in such a way that minimizes both the total fixed and variable operating cost. This paper focuses on the development of such a plan. The structure of this paper is as follows. In section 2, we provide a brief description of the network structures and operations of multi-modal express services. It is followed by a review of relevant research in section 3. In section 4, we formulate the fleet planning problem for the multi-modal express services as an integer program. In section 5, we give a detailed description of our proposed complete enumeration algorithm with an embedded constrained minimum spanning tree subproblem. The largest LTL carrier's network is used in section 6 to evaluate the efficiency and effectiveness of our algorithm which was tested on the top three air express districts.

2. OPERATIONS FOR EXPRESS SERVICES

Time definite common carriers typically divide Taiwan into several express districts (see Figure 1) with an operations network that mainly consists of three types of facilities: hub, spoke, and drop-off. Drop-off facilities only accept shipments while spokes accept shipments and also deliver them to consignees. All the pickup or delivery operations are provided by small package cars. Finally, hubs perform volume consolidation by unloading volume from a fleet of intra-district vehicles, sorting and reloading them into a fleet of inter-district long haul tractor-trailers and vice versa.

The overall operations network structure consists of two sub-networks: *line-haul operations* and *local service*. The line-haul operations network is basically a hub-and-spoke system with an additional 'forest' network structure. The '*forest*' consists of a group of '*trees*', which is an express district that contains only one hub that serves all its spokes. The root of the 'tree' is the hub of the district. Spokes in the district are directly or indirectly connected to the hub. All the roots of the 'trees' are connected by the National Highway System.

A pair of 10.5 tons inter-district tractor-trailers are dispatched every working hour. One heads south on the National Highway System from the hub of the farthest north express district while the other heads north on the National Highway System from the hub of the farthest south express district. Each tractor-trailer stops at the hub of each district to unload its delivery shipments and load shipments to other districts. A hub also sorts delivery shipments for each delivery spoke when it receives delivery shipments of its own. It normally takes approximately 10-15 minutes for a consolidation operation. Several intra-district vehicles are dispatched to spokes (see Figure 2) upon completion of the consolidation. They are 3.5 tons vehicles. Each vehicle covers a few spokes. Each travels on an *outbound* path that is a pre-determined sequence of its assigned spokes. At each spoke, each vehicle unloads delivery shipments and loads delivery shipments destined for other spokes on the remaining path. Drivers turn around and start traveling on an *inbound* path, which is the same as the outbound except in reverse sequence, at the last spoke of the outbound path. The *maximum intra-district service time* (including hub consolidation duration) is two hours. The *maximum path time* of either outbound or inbound deliveries is, therefore, an hour at most. A vehicle completes one hub operation and one unloading-loading time at the end-of-path spokes and two unloading-loading times at all intermediate spokes during a complete journey. Therefore, only half of the hub operation and unloading-loading time at the end-of-path spoke should be counted when calculating the outbound or inbound path time. Each district has to equip two fleets of intra-district vehicles because a pair of inter-district, long-haul tractor-trailers visit the hub every hour.

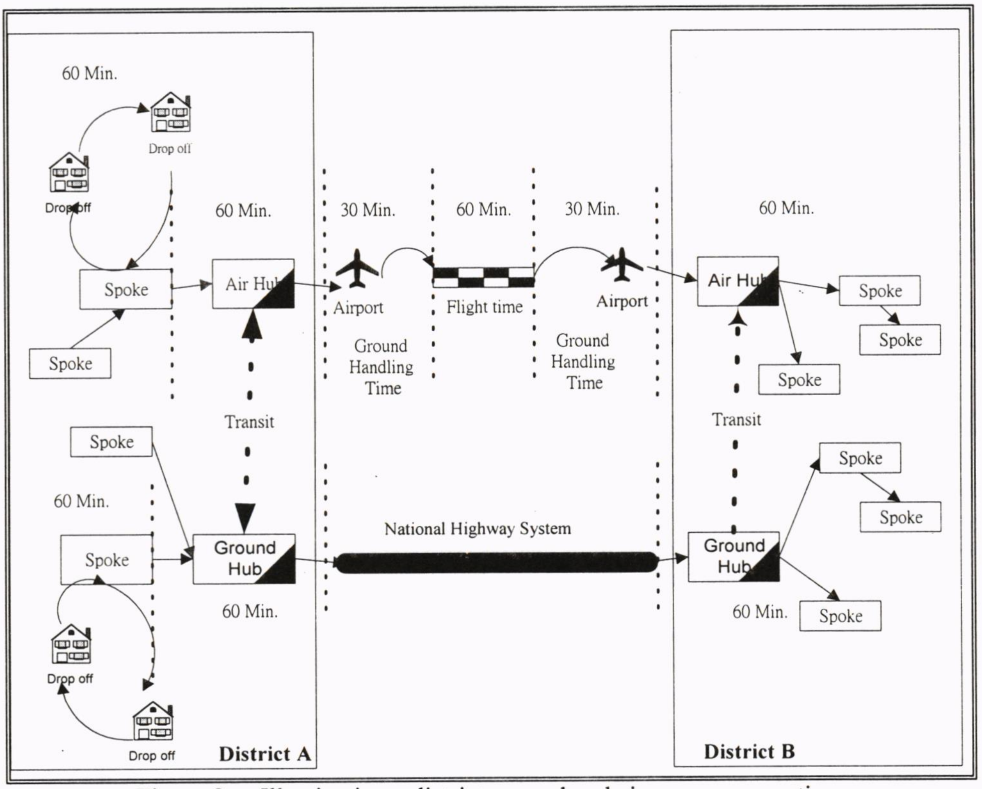

Figure 2: Illustive intra-district ground and air express operations

A spoke loads and then dispatches a fleet of 800cc mini-cars and/or motorcycles after receiving its delivery volume, while simultaneously picking up new shipments from dropoffs. Each car has its assigned service territory, which has a tour (an alternative name is cycle) that takes no more than 30 minutes to complete. Thus, each vehicle executes two tours of pickup volume for one intra-district. The service commitment (or timetable) depends on which chain of vehicles (package car, intra- and inter-district vehicles) that shippers' employ. For example, on an average, the maximum travel time of a chain of vehicles between Taipei and Kaohsiung is of 8 hours which becomes the service time to customers requiring this service.

The same-day air express operations network is almost identical to that of the same-day ground system since an air hub serves all the spokes in each air express district. The only difference is that carriers contract their inter-city movements to interested airlines instead of running inter-district, long-haul tractor-trailers. The service commitment target is 4 hours between any two cities (see Figure 2). A package is deplaned, cleared after approximately 30 minutes, and then rushed to the air hub of the district where the intra-district operations start. Similar to the same-day ground operations, air intra-district operations include volume consolidation at the hub, delivering volume to spokes on an outbound path and picking up new shipments via an inbound path. The *maximum path time* for each route is also 60 minutes.

To provide multi-modal express services, carriers cannot run two operations side by side and expect to be cost effective. As a result, this study aims to help carriers determine the most cost effective, integrated fleet to simultaneously service the air and ground express markets while meeting the time commitments of an express district. Since, all same-day express shipments are small and light-weighted, in practice, there is no vehicle capacity problem. Thus, in this study, it is ignored.

3. LITERATURE REVIEW

Since time definite freight delivery is a multi-billion dollars operation, reducing unnecessary costs is an important strategy to improve profit. Operations Research (OR) has helped carriers operate more efficiently by determining an efficient line-haul operating plan that involves a complex decision process. Carriers typically use a sequential decision process that consists of three phases: the determination of freight routes, the assignment of trailers to loads, and the construction of schedules for feeder drivers. Carriers may alternate the network by opening or closing hub facilities and/or re-configure its feeder fleet over the long-term.

Carriers must determine freight routes that minimize the operating cost under the available network capacity (Lin, 1996), as well as determine trailer combinations to move freight between facilities with a minimum cost (Eckstein and Sheffi, 1987; Lin, 1991). Load planning integrates the freight routing and trailer assignment. Powell and Sheffi (1989) examined how a time indefinite LTL trucking company could consolidate small shipments through the carrier's consolidation network to minimize the overall handling and transportation cost while maintaining the minimum service frequency and operational restrictions. On the other hand, Leung, et al. (1990) developed a system to solve the load planning for the time definite delivery industry. They suggested three methods: marginal cost, capacity directed heuristics, and two-staged decomposition approach. Their study only considered a single trailer type on the highway mode, even though most carriers use several types of trailer equipment on different transportation modes to achieve the lowest operating cost. Lin (1990) extended their single-modal and single-type load planning for multi-modal and multiple trailer equipment types. He decomposed the problem down into routing and equipment assignment subproblems and proposed an efficient algorithm for each subproblem. Finally, a feeder driver scheduling assigns loads to drivers while meeting labor regulations when loads are determined (Suter, et al., 1996).

Most studies that examine how to determine where to locate hubs so that the overall cost is minimized are for air express common carriers. Chestler (1985) described, while Hall (1989) analyzed, the justification for a hub-and-spoke network structure. Hall pointed out that the single hub should be located in an earliest time zone possible to minimize the service time between any pairs of origin-destination while maximizing the window of freight processing time at the hub. A national and a regional twin-hub network will be the most cost-effective operation when there is more than one hub. Employing differential equations to study the location of hubs, O'Kelly (1986) pointed out that the location decision for a one-hub network is the same as that for a Weber least cost location model. Hubs will locate as far away from each other as the transport economies of scale allows in a twin hub network.

All the research above assumes there are no direct connections between spokes. However, Kuby and Gray (1993) not only allowed for connection between spokes, but also permitted aircraft to service other spokes for loading and unloading before going to the hub. Using Federal Express secondary data for numerical testing, they showed that the load factor is higher and the overall cost is lower than when carriers do not take advantage of stopover operations. On the other hand, Current (1986,1988) generated several k-shortest major corridors in his hierarchical network design. He, then, used the minimum spanning tree algorithm to connect spokes that are not on the major corridor.

Barnhart and Schneur (1996) designed a line-haul operations model for air carriers who provide a single express (overnight) service that determines aircraft routes and schedules, and ground feeder and freight routes for a one-hub network. Our research shifts focus to emphasize how to determine a single-modal (ground) fleet that simultaneously serves as a multi-modal express service.

4. MATHEMATICAL FORMULATION

The maximum path (service) times for air and ground express operations are denoted as $\hat{T}^a, \hat{T}^g$, respectively. The *six* possible fleet types that carriers may dispatch to provide the same-day air and ground express services are:

(1) Air-via-ground fleet [*ag*]. Dispatched at the air but transported via the ground hub prior to serving other spokes. Its maximum service time is $\hat{T}^{ag} = \hat{T}^a$.

(2) Air-waiting-for-ground fleet [*a(g)*]. Dispatched at the air hub but does not depart until a vehicle *ga* has arrived, its maximum service time is $\hat{T}^{a(g)} = \hat{T}^a - t_{ga}$.

(3) Air fleet [*a*]. Dispatched at the air hub and serves air shipments only. Its maximum service time is $\hat{T}^a$.

(4) Ground-via-air fleet [*ga*]. Dispatched at the ground but transported via the air hub prior to serving other spokes. Its maximum service time is $\hat{T}^{ga} = \hat{T}^g$.

(5) Ground-waiting-for-air fleet [*g(a)*]. Dispatched at the ground hub, but does not depart until a vehicle *ag* has arrived. Its maximum service time is $\hat{T}^{g(a)} = \hat{T}^g - t_{ag}$.

(6) Ground fleet [g]. Dispatched at the ground hub and serves ground shipments only, its maximum service time is $\hat{T}^g$.

Air-only (a) and ground-only (g) are termed *single-modal* fleets, while all others are *multi-modal* fleets. A multi-modal-service spoke can be served by one of the following four multi-modal fleets: *ag, a(g),ga, g(a)*. It could also be served simultaneously by both single-modal fleets $\{a,g\}$. Alternatively, a ground-service-only spoke can be served by all except the a fleets (see Table 3). When there is no vehicle capacity restriction, there is at most one air-via-ground (and a ground via air) vehicle in the solution because all others may be dispatched as ground-waiting-for-air vehicles. The total operating cost may be reduced by a round-trip between the air and ground hubs when the second vehicle and above are converted.

Table 3: The suitable fleet types

Spoke type	**Services**	**Fleet type**					
		Air-via-ground(*ag*)	Ground-via-air(*ga*)	Air-wait-for-ground(*a(g)*)	Ground-wait-for-air(*g(a)*)	Air (*a*)	Ground (*g*)
Multiple	Air	✓	✓	✓	✓	✓	--
	Ground	✓	✓	✓	✓	--	✓
Ground-only	Ground	✓	✓	✓	✓	--	✓

An integer program for fleet planning multi-model services is presented below. The notations are defined as follows:

4.1 Parameters

O: the set of air and ground hubs with generic element $o \in O = \{o^a, o^g\}$,
M: the set of multi-modal-service spokes, with generic element m; $m \in M$,
N: the set of ground-service-only spokes, with generic element n; $n \in N$,
i, j: indexes for spokes; $i, j \in M \cup N$,
K: the set of fleet types, with generic element $k \in K = \{ag, a(g), a, ga, g(a), g\}$,
P^k: the set of possible routes (whether path time feasible or not) for fleet type k; $k \in K$,
c_p^k: the travel cost of p^{th} route of fleet type k; $p \in P^k, k \in K$,
c: the fixed cost for an intra-district vehicle,
t_{ij}: the travel time on link ij; $i, j \in M \cup N$,
t_o: the consolidation duration of hub facility $o \in O$,
$\hat{T}^k$: the maximum path time of fleet type k; $k \in K$,
$\delta_{ij,p}^k$: =1, if link ij on the p^{th} route
=0, others; $i, j \in M \cup N, \forall p \in P^k, k \in K$,

4.2 Decision Variables

h_p^k: =1, if p^{th} route is chosen,
=0, others, $p \in P^k, k \in K$,
y^{ag}: =1, if an air-via-ground vehicle path is chosen
=0, others

y^{ga} : =1, if a ground-via-air vehicle path is chosen
=0, others

4.3 Mathematical Formulation

$$\min z = \sum_k \sum_p (c_p^k + c) h_p^k \tag{1}$$

subject to:

$$\sum_{ij} \delta_{ij,h_p^k} t_{ij} h_p^k \le \hat{T}^k ; \qquad \forall p \in P^k, k \in K \tag{2}$$

$$\begin{cases} \sum_p h_p^{ga} = y^{ga} \\ \sum_p h_p^{a(g)} \le B y^{ga} \end{cases} \tag{3}$$

$$\begin{cases} \sum_p h_p^{ag} = y^{ag} \\ \sum_p h_p^{g(a)} \le B y^{ag} \end{cases} \tag{4}$$

$$\sum_{k \in \{ag, a(g), a, ga\}} \sum_p \sum_i \delta_{ij,p}^k h_p^k = 1; \qquad \forall j \in M \cup N \tag{5}$$

$$\sum_{k \in \{ag, a(g), g(a), g\}} \sum_p \sum_i \delta_{ij,p}^k h_p^k = 1; \qquad \forall j \in N \tag{6}$$

$$h_p^k, y^{ga}, y^{ag} \in \{0,1\} \qquad \forall p \in P^k, k \in K \tag{7}$$

The objective is to minimize the sum of transportation and fixed vehicle costs for an express district. Constraint (2) declares that the path time of any vehicle can not exceed the maximum for all vehicle types. Constraint (3) declares that we may dispatch air-waiting-for-ground vehicles (*a(g)*) only when there is a ground-via-air vehicle (*ga*) is dispatched. *B* denotes a large number. Thus, when no ground-via-air vehicles are dispatched, $y^{ga} = 0$, then carriers can not dispatch any air-waiting-for-ground vehicles, $\sum_p h_p^{a(g)} \le 0$. On the contrary, when carriers dispatch a ground-via-air vehicle, $y^{ga} = 1$, there is no restriction on the number of air-waiting-for-ground vehicles that may be dispatched, $\sum_p h_p^{a(g)} \le B$. A similar condition applies to air-via-ground and ground-waiting-for-air fleets as stated in constraint (4). Constraint (5) declares that one vehicle either rooted at or via the air hub must provide the air service for multi-modal-service spokes. Similarly, a vehicle either rooted at or via the ground hub must serve all spokes since all spokes provide ground-only service. Of course, there is only one vehicle required to serve a multi-modal-service spoke when a vehicle of $\{ag, a(g), ga, g(a)\}$ stops over both hubs. A final constraint is that all decision variables must satisfy the zero-one binary restriction.

5. ALGORITHM

Since the largest express district of the largest time definite carrier in Taiwan has only twelve spokes, a complete enumeration with an embedded degree and time constrained minimum spanning tree (DTMST) algorithm can serve to calculate the most efficient operating system. There are at most a total of $|M|^6|N|^5$ combinations in the implementation of a complete enumeration approach because a multi-modal-service spoke can be served by one of four multi-modal fleets $\{ag, a(g), ga, g(a)\}$ or two single-modal fleets simultaneously $\{a, g\}$, while a ground-service-only spoke can only be served by one of five fleets. A combination is each spoke is assigned to a feasible fleet type for all spokes in the express district.

However, the number of combinations, $|M|^6|N|^5$, may be reduced because there is optimally one air-via-ground vehicle and one ground-via-air vehicle. This implies that each multi-modal-service spoke can be assigned to one of four fleets, $\{g(a), a(g), a, g\}$. Of course, the other single-modal fleet must be dispatched when one of two single-modal fleets is assigned. However, one of the ground-waiting-for-air (air-waiting-for-ground) vehicles is converted into an air-via-ground (ground-via-air) vehicle in the solution to ensure that constraints (3) and (4) are satisfied. On the other hand, each ground-only spoke can be served by one of three fleets, $\{g(a), a(g), g\}$. The set of total combinations is denoted as Ω, which means that the total number of combinations is reduced to $|\Omega| = |M|^4|N|^3$. Four types of fleets $\{g(a), a(g), a, g\}$ need to be solved and converted, if necessary, in each combination. Thus, the fleet planning problem (1)-(7) may be decomposed into a sub-problem for each fleet type. When fleet type $\bar{k} \in \{a(g), g(a), a, g\}$ is denoted as its associated hub $o(\bar{k})$ and the set of spokes assigned to $\bar{k}$ as $N(\bar{k})$, each subproblem becomes:

$$\min z(\bar{k}) = \sum_p (c_p^{\bar{k}} + c) h_p^{\bar{k}} \tag{8}$$

subject to:

$$\sum_{ij} \delta_{ij, h_p^{\bar{k}}} t_{ij} h_p^{\bar{k}} \le \hat{T}^{\bar{k}}; \qquad \forall p \in P^{\bar{k}} \tag{9}$$

$$\sum_p \sum_i \delta_{ij,p}^{k} h_p^{\bar{k}} = 1; \qquad \forall j \in N(\bar{k}) \tag{10}$$

$$h_p^{\bar{k}} \in \{0,1\} \qquad \forall p \in P^k, k \in K \tag{11}$$

Subproblems (8)-(11) are shown to be completely equivalent to the degree and time constrained MST subproblem to prevent the explicit determination of all possible routes (Lin, 1998).

$$\min z(\bar{k}) = \sum_j c y_{o(\bar{k})j} + \sum_{ij} c_{ij} y_{ij} \tag{12}$$

subject to:

$$\sum_{ij} t_{ij} x_{ij}^{l} \le \hat{T}^{\bar{k}}; \qquad \forall l \in N(\bar{k}) \tag{13}$$

$$\sum_{i} x_{ij}^{l} = 1 \qquad \forall j \in N(\bar{k}) \tag{14}$$

$$\sum_{l} x_{ij}^{l} \le B y_{ij}; \qquad \forall i,j \in N(\bar{k}) \tag{15}$$

$$\sum_{i}\sum_{j} y_{ij} = \left|N(\bar{k})\right|; \tag{16}$$

$$\sum_{i} y_{ij} + \sum_{k} y_{jk} \le 2; \qquad \forall j \in N(\bar{k}) \tag{17}$$

$$x_{ij}^{l}, y_{ij} \in \{0,1\} \qquad \forall i,j \in N(\bar{k}) \tag{18}$$

where x_{il}^{l}=1, if the delivery volume of spoke l is flown on link ij;
=0, otherwise
y_{ij}=1, if a vehicle is traveled on link ij;
=0, otherwise

The objective function (12) is the sum of the fixed vehicle and operating costs which is the same as (8). Constraint (13) declares that the total path time from the hub to any spoke can not exceed the maximum path time. Constraint (14) declares that there is only one path to any spoke. Constraint (15) declares that there are flows on a link only when there is a vehicle assigned to it. Constraint (16) declares that the total number of links that have vehicles assigned to them is exactly one less than the total number of nodes (including spokes and the hub). Constraint (17) declares that the maximum degree of each node is two. Constraints (16) and (17) imply that all the intermediate nodes have a degree of two and all end-of-path nodes have a degree of one. Therefore, the subproblem is finding a MST with degree and time constraints of (17) and (13).

The structure of the algorithm (shown in Figure 3) is described as follows.

Step 0. **Initialization**. Set $z^{*} = \infty$, and $h_{p}^{k^{*}} = \{0\}$.

Step 1: **Select a combination**. Select a combination $\{N(\bar{k}), \bar{k} \in K\} \subset \Omega$. Set $z^{*}(N(\bar{k}), \bar{k} \in K) = 0$, and continue to step 2 when the combination is legitimate or terminate the program when it is otherwise. The current incumbent solution is a local optimum except when there is no feasible solution to the fleet planning problem, when $z^{*} = \infty$.

Step 2. **Select a fleet type**. Select one of four fleets, $\bar{k} \in K$, an associated hub $o(\bar{k})$, and an $N(\bar{k})$ for $\{N(\bar{k}), \bar{k} \in K\}$. Calculate the total operating cost $z^{*}(N(\bar{k}), \bar{k} \in K)$ for $\{N(\bar{k}), \bar{k} \in K\}$, and go to step 6, if there is no fleet type is selected.

Step 3. **Generate a MST**. A minimum spanning tree must be determined without considering any side constraints for $N(\bar{k})$, $\bar{k} \in K$ by implementing the Kruskal greedy algorithm (Kruskal, 1956). Go to step 1, where there is no MST. Otherwise, go to step 2.

Step 4. **Verify degree constraint**. If there exists a $j \in N(\bar{k})$ such that $\sum_i y_{ij} + \sum_k y_{jk} > 2$, select $\overline{ij} : c_{\overline{ij}} = \max\{c_{ij}, c_{ji}, i, j \in N(\bar{k})\}$, set $c_{ij} = \infty$ and return to step 3.

Step 5. **Verify path time constraint**. If there exists a $l \in N(\bar{k})$ such that $\sum_{ij} t_{ij} x_{ij}^l > \hat{T}^{\bar{k}}$, and the path is $\{x_{o(\bar{k})i_1}^l, \ldots, x_{i_n i_{n+1}}^l, \ldots\}$, select $\overline{i_n i_{n+1}} : \sum t_{i_n} + t_{i_{n-1} i_n} \le \hat{T}^{\bar{k}}; \sum t_{i_n} + t_{i_n i_{n+1}} > \hat{T}^{\bar{k}}$, and set $c_{\overline{i_n i_{n+1}}} = \infty$. Return to step 3, if the first link on the path violates the maximum path time; otherwise, return to step 2.

Step 6. **Update the incumbent solution**. If $z^*(N(\bar{k}), \bar{k} \in K) < z^*$, then $z^* = z^*(N(\bar{k}), \bar{k} \in K)$, and $h_p^{k^*} \leftarrow \{x_{ij}^l, l \in N(\bar{k})\}$. Return to step 1.

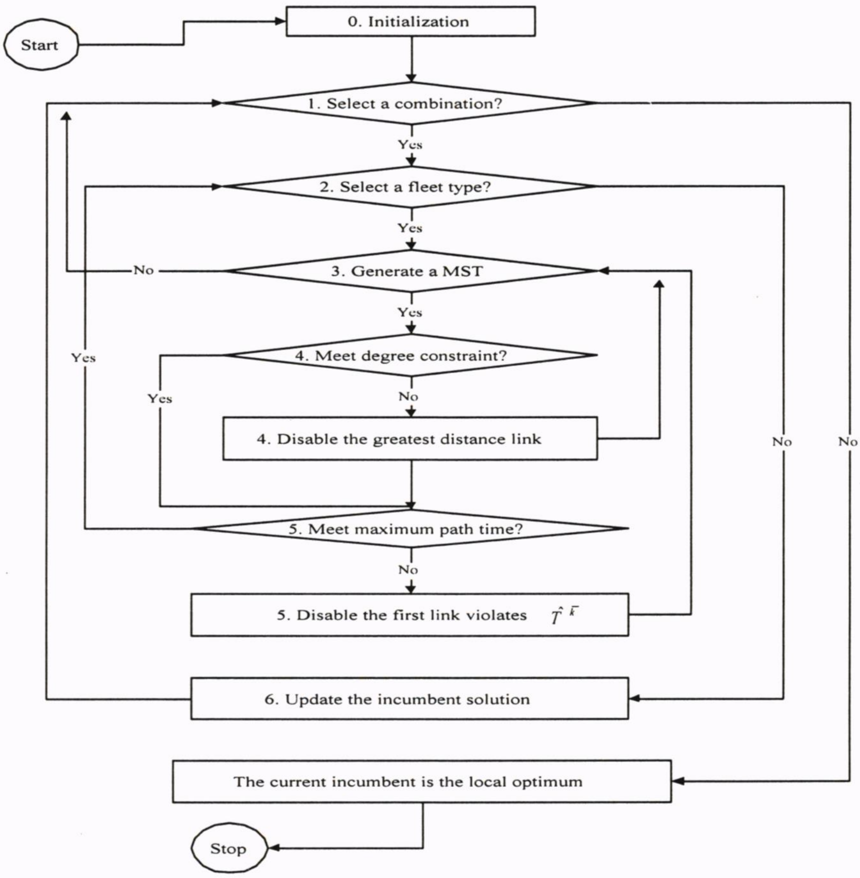

Figure 3: Flowchart of the complete enumeration algorithm

6. COMPUTATIONAL RESULTS

The program is coded in C language and computationally tested via a Linux operating system on a Pentium Pro PC with a CPU speed of 200 MHz. We choose such a platform over others is because PCs are the most common platforms for carriers in Taiwan. The largest time definite carrier in Taiwan was used for numerical testing. The fixed and transportation variable costs of an intra-district vehicle are shown in Table 4.

Table 4: Cost structure

Cost items		Cost(NT$)
Variable Cost	Maintenance and Fuels (NT/K.M.)	3.19
Fixed Cost	Depreciation (Per trip)	65
	License tax (Per trip)	1.53
	Fuel tax (Per trip)	2.63
	Driver's salary (Per trip)	113.64

Currently, the top three carrier districts on the island (Figure 1 details the 13 districts) are Taipei, Taichung and Kaoshiung, each of which consists of 12, 7, and 5 spokes, respectively. The carrier now only provides the same-day ground express service. The ground hub of the Taipei district is in Lucho. The existing operating plan (see Figure 4) assigns six vehicles to serve the other eleven spokes.

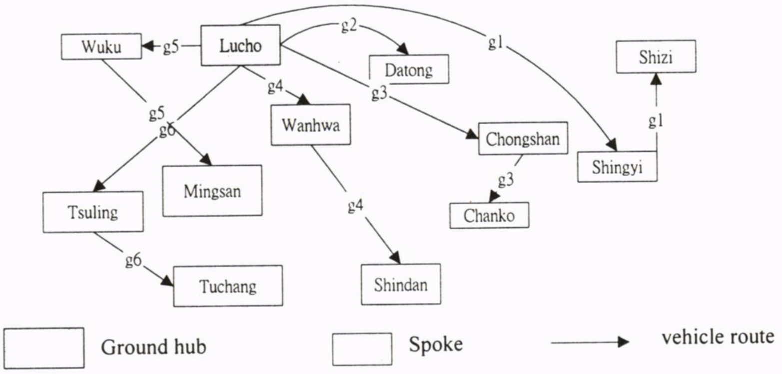

Figure 4: Existing ground express service network in Taipei district

One test was conducted in each of the three districts. The testing parameters (consult Table 5), included the number of multi-modal-service and ground-service-only spokes, and the average speed of each district. The spoke closest to the airport was selected as the air hub of the district despite the fact that the carrier does not currently provide same-day air express service. Although, the air and ground hubs are different in Taipei and Kaohsiung districts, Dahtwen is both an air and ground hub in Taichung district.

Table 5: numerical testing parameters

District	Spokes		Hubs		Speed (km/hr)
	Multiple	Ground	Air	Ground	
Taipei	5	7	Chongshan	Lucho	35
Taichung	3	4	Dahtwen	Dahtwen	45
Kaohsiung	3	2	Fengshan	Nantzyy	55

The computational results including the current ground fleet and their operating cost, the fleet size and modal operating costs of two separate fleets serving different demands, and the fleet size of the integrated fleet serving both air and ground demands are organized for all three districts in Table 6. Overall, the computational times are fairly reasonable. The longest computation time is less than 10 minutes. This computation performance is typically within planner's tolerance.

Table 6: Computational results

District	Fleet											
	Existing		Two separate							Integrated		
			Ground			Air			Total			
	Size (vehicle)	Cost (NT)	Size (vehicle)	Cost (NT)	cpu (sec.)	Size (vehicle)	Cost (NT)	cpu (sec.)	cost (NT$)	Size (vehicle)	Cost (NT$)	cpu (sec.)
Taipei	6	1748.2	5	1485.65	549.62	2	467.68	0.11	1953.33	6	1626.98 (-16.7%)	248.5
Taichung	4	1260.1	3	1093.89	0.72	1	230.01	0.02	1323.9	3	1093.89 (-17.4%)	1.44
Kaohsiung	2	582.5	2	601.66	0.06	1	275.31	0.02	876.97	2	646.32 (-26.3%)	0.09

The existing six vehicles ground fleet for Taipei district would not require any increase if air service is introduced into the district. Chongshan was chosen as the air hub of the existing five spokes because of its central location. The aggregate cost is NT$1953.33 if two separate fleets are maintained. However, since an integrated fleet requires one less vehicle, the carrier may realize a saving of 16.7%.

Current fleet planning is not as efficient as should be since the total cost for the integrated fleet is NT$1626.98 is lower than the current fleet cost of NT$1748.2. Moreover, existing same-day ground operations can utilize 5 instead of 6 vehicles. The algorithm is capable of identifying a cost effective operating plan since, one vehicle reduction is demonstrated to save 15% in cost for the carrier.

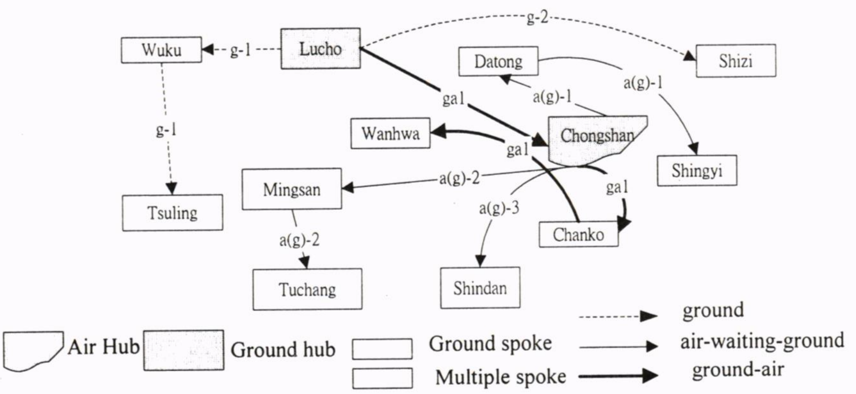

Figure 5: The local optimum of fleet planning for multiple services in Taipei district

Since several ground-service-only spokes are indirectly served by the air hub, the local optimum routing does not call for dispatching ground vehicle to directly serve all ground-service-only spokes. A comparison of the vehicle routes for the integrated and two separate fleets reveals a similar conclusion. The former uses the newly introduced air hub, Chongshan to serve its nearby ground-only spokes, such as Shindan, while one (instead of two) vehicles heads to the spokes in the east and south-east areas of the Taipei district.

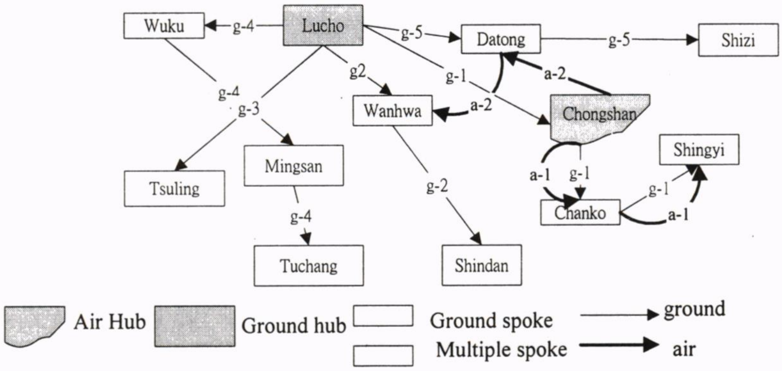

Figure 6: The local optimum of two exclusive fleets in Taipei district

The Taichung and Kaoshiung express districts also require one less vehicle if an integrated fleet is dispatched instead of two separate fleets. This change results in savings of 17.4% and 26.3% for each district.

7. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Time definite carriers in Taiwan traditionally concentrate on next-day ground service for shippers. The increasing demand for same-day air and ground express service has prompted carriers to introduce related products. Carriers normally provide two types of express services in sequence, ground prior to air. Carriers must make provisions to integrate their fleet when providing multi-modal express services in order to reduce the overall operating cost. The integer program developed and successfully tested herein can help a carrier develop the most cost-effective, integrated multi-modal transportation network possible. Among the several research possibilities is to see whether it is even more cost effective to have more than one air or ground hub in each district. Secondly, since this study focused on how to minimize cost, questions remain about how to maximize profit. Carriers would like to cover all the markets as long as they make a profit. In order words, when determining their air express market for example, they will only exclude areas with no profit margins. Thus, studying the possibly profitable air express service territories could be another are of inquiry.

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