THE FEEDER SCHEDULING PROBLEM FOR TIME-DEFINITE GROUND DELIVERY COMMON CARRIERS

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Abstract: The time-definite freight delivery common carriers provide door-to-door time guaranteed small shipment delivery services for shippers. The pure hub-and-spoke network consolidates partial loads with the result of lower operating cost, is the most common operations configuration for the industry. The operations planning determine freight routes, balanced trailer movements, and feeder schedules to guide daily operations. The feeder scheduling problem is to determine a minimum cost assignment of feeder drivers to planned loaded and empty trailer movements while meeting the work rules. We explored the special characteristics of the problem. As the result, the size of schedule patterns set is substantially reduced. In addition, the problem is modeled as an integer program instead of classic set partitioning problem. We used the operations network of the third largest common carrier in Taiwan with randomly generated demands for numerical testing. A very effective computational result demonstrates the approach is capable for practical implementation.

Key Words: freight transport, hub-and-spoke network, scheduling problem

1. INTRODUCTION

The time-definite freight delivery common carriers collect, transport and deliver time-guaranteed small shipments for shippers. They offer services to the general public. They serve and may not discriminate whomever pay for their publish tariffs. Therefore, they are classified as *common* carriers. To be a competitor in the market, carriers must design an effective delivery network along with an efficient operational plan. The *pure hub-and-spoke network* consolidates partial loads with the result of lower overall operating cost, is the most commonly used network configuration by the carriers (Akyilmaz, 1994; Bryan and O'Kelly, 1999; Chestler, 1985). A complete cycle of door-to-door delivery operations in a pure hub-and-spoke network, illustrated in Figure 1, constitutes the *local service* and *line-haul operations* (Lin, 2001). There are two types of facilities in the network, a large number of scattered *centers* with ease of accessibility to customers and a relative small number of *hubs* located in the central locations of centers. Each center has an assigned geographic service area. In the beginning of each business day, a fleet of *package cars* is dispatched to deliver shipments to consignees. This marks the beginning of a cycle of local service operations. In the late afternoon, they pick up new shipments from shippers. When package cars return to their respective centers, it ends the local service operations. This, on the other hand, also marks the beginning of line-haul operations.

At twilight, each center runs a *local sort* to unload fright from the package cars, sort and reload them unto a fleet of *long-haul feeders*. Feeders are tractors hauling various types of trailers feeding freight between facilities. At the end of the sort, long-haul feeders are dispatched to hub sorts of various hubs for consolidation. Hubs consolidate inbound freight fed from center local sorts and/or hub sorts of other hubs. Every hub runs at least a sort, *Night* sort for center pickups. However, to increase their utilization, hubs would run as many sorts as time permits and volume is available. At any sort, inbound loads are unloaded, sorted and reloaded unto an outbound feeder fleet. They are then dispatched to center *preload sorts* for delivery or to hub sorts of other hubs for further consolidation. Before dawn, each center receives its delivery volume. Each center runs a *preload* to unload freight from the long-haul feeders, sort and reload them onto a fleet of package cars for delivery. This completes a cycle of line-haul operations, but starts a new cycle of local service operations.

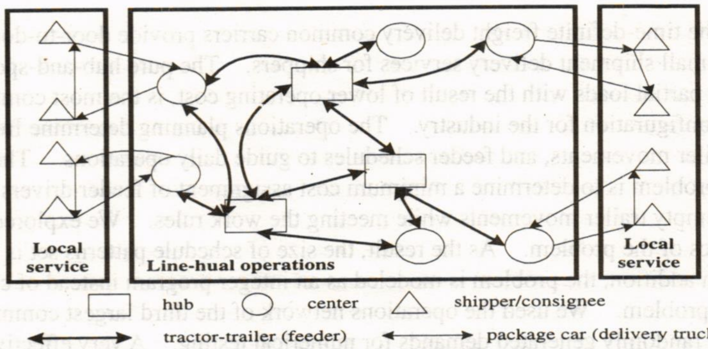

Figure 1: Delivery network in a pure hub-and-spoke network

To design a cost-effective line-haul operational plan involves complicated and mutually interactive decisions. A sequential decision approach is normally adopted. The *freight routing plan* determines routes to minimize the operating cost in a capacitated line-haul operations network while meeting the level of service and operational restrictions (Lin, 2001). Knowing the freight routes; the *trailer assignment and balancing plan* determines a balanced trailer network for each of all trailer types with sufficient carrying capacity to transport freight between facilities (Eckstein and Sheffi, 1987). Lastly, the *feeder scheduling plan* determines feeder driver schedules to minimize the feeder operating cost while meeting their work rules (Suter, et al., 1996).

In the past, the airline crew-scheduling problem has drawn an extensive research. It is to determine crew schedules to serve the planned flights with a minimal cost while meeting the work rules. However, the feeder scheduling problem has some intricate characteristics making itself a unique research topic. They include adjustable but required daily return to driver bases, adjustable departure and arrival times, relay for long-haul loads and multiple loads over the same segments.

In this research, our goal is to analyze the intricate characteristics of feeder scheduling problem. This paves the way for an efficient algorithmic design. The structure of this paper is as follows. In section 2, we discuss in-depth the intricate characteristics of feeder scheduling problem. Based on those characteristics, we develop a set of strategies for algorithmic design. In section 3, we formulate the feeder scheduling problem in path formulation as an integer program. However, it differs from the airline crew-scheduling problem that requires the decision variables to be binary. The integer programming formulation allows us to define columns in terms of schedule patterns instead of each individual schedule. This strategy may reduce the problem size and increase the computational efficiency. In section 4, we develop a heuristic approach for the problem. The approach consists of three modules, raw schedule pattern construction, evaluation and complete schedule construction. In section 5, we use a partial and a complete line-haul operations network of the third largest freight delivery common carrier for numerical testing. We compute and compare the local optimal solution again the exact solution to evaluate the performance of the heuristic approach in the partial network. Subsequently, we solve and show the results for the complete network. The conclusions and future research is summarized in section 6.

2. THE INTRICATE CHARACTERISTICS

The airline crew-scheduling (CS) problem is to determine a minimum cost assignment of crews to planned flight schedules under the restriction of work rules. Let us review some basic definitions (Vance, et al., 1997). A *flight segment* is a non-stop flight. A *duty period* consists of a sequence of flight segments with a briefing and a debriefing at the beginning and ending of the period. A *pairing* is a sequence of duty periods with sufficient rests in between. The airline CS problems are classified into domestic and international CS problems. The domestic CS assumes every flight is flown daily. The hub-and-spoke network creates more connections for crews that complicates the domestic CS problems. Chu, et al. (1997) studied daily duty pairing, while Vance, et al., (1997) and Hoffman and Padberg (1993) studied crew-pairing optimization. Desaulniers, et al., (1998) provided a unified formulation for the CS problems.

Much of the work solves the CS problems in two stages, pairing generation and evaluation (Etschmaier and Mathaisel, 1985). The pairing generation module creates a set of feasible and reasonable good candidate pairing. The pairing evaluation module, on the other hand, determines a minimum cost assignment. It, in most case, is formulated as a set partitioning problem. The pairing generation module, in terms, uses the reduced costs determined by the evaluation module to generate additional schedules with negative reduced costs. A basic (non-basic) schedule has zero (positive) reduced cost. Thus, they won't be re-generate again by the pairing generation. Thus, at the (local) optimum, all schedules are non-repetitive. As will be discussed below, one of the intricate characteristics of feeder scheduling problem is that there are multiple loads over the same feeder segments. There may have several repetitive schedules at optimality. Thus, the classic CS approach with non-repetitive assumption cannot be directly applied.

In this research, the feeder scheduling problem is a daily problem. That is, every planned loaded or empty trailer is hauled every day. Thus, it is the same as a domestic daily duty pairing optimization problem in the airline industry. There are several distinguished characteristics embedded in the feeder scheduling problem that differentiate itself from the vast research in the CS for the airline industry. In this section, we describe in detailed the intricate characteristics of feeder operations of the time-definite freight delivery industry. Such an in-depth analysis may allow us to trim off a large portion of feasible but non-optimal feeder schedules. A smaller feasible region may potentially reduce computational times. The quicker in computation, the higher the successful for us to implement time-consuming exact algorithms. At the end of this section, we will discuss the strategic implications of those characteristics. The operational description will be based on the following assumptions.

1. *Tractor hauls a single detachable trailer*. Carriers currently use a few trailer types and tractor-trailer combinations. The common ones in US include 28' and 45'. The single is a tractor hauling a 28' trailer while the double hauls a twin-trailer. The 45' trailers are mainly for rail transport. All the trailers are detachable from tractors. In Taiwan, on the other hand, there are three types of feeders, tractor hauling a non-detachable trailer, single and double. In this research, we assume that tractor hauls a single detachable trailer. The reason is that this arrangement provides an additional advantage. That is, if necessary, tractor-only, called *bobtail* in practice, can travel between facilities to haul trailers. This implicitly assumes that the carriers have a homogeneous tractor and trailer fleet.

2. *Wait and idle times are paid hours*. We assume that the driver's wait and idle times are paid hours the same as the on road hours. They are also parts of driver's working hours.

3. *No overtimes*. In this research, we do not consider driver overtimes. However, carriers may alternate the number of workdays per week. As the case in Taiwan, a 10.5-hour for 4 days a week will be paid the same as an 8.4-hour for 5 days a week. This strategy allows the carriers to schedule long haul loads without dividing them into small segments for several drivers with potential of bobtails.

The intricate characteristics are described as follows.

1. *Bobtails*. Bobtails are practical terminology for *tractor-only* movements. When facilities are near by, carriers sometimes schedule one way bobtail coupled with tractor-trailer movement on the other way to save an additional feeder driver.

2. *Adjustable but required daily return to driver bases*. Any of the carrier's facilities, a center or hub, can be designated as the home base for drivers. When assigned, drivers must complete their daily schedules at where they depart.

3. *Adjustable actual departure and arrival times*. For each load, there is an associated time window, that is, the combination of the earliest available (EA) and latest arrival (LA) times. Loads are only available when consolidation completes and are required to be available when sort starts. Thus, EA is exactly the sort end of origin sort while LA is the sort start of destination sort. However, most loads do not take up whole time windows for transport. Thus, carriers may start drivers at when the loads will actually make the latest arrival times and eliminate driver's wait times.

4. *Relay for long-haul loads*. To meet the daily return rule, long-haul load must be relayed by a set of drivers, if it takes up more than a half of driver's daily work hours to transport.

5. *Multiple loads over the same segments*. In practice, most center local sorts make multiple loads to each of selected hub sorts for consolidation. Similarly, most of hub sort feeds multiple loads to each of served center preload sorts for delivery.

6. *Empty repositioning*. A complete delivery cycle starts at center local sorts and ends at center preload sorts. At the end of the cycle, some centers end up with extra trailers than necessary for the next daily cycle. On the other hand, some centers are in shortage. Thus, during day times, carriers need to reposition empties for next daily cycle.

The strategic implications of the above intricate characteristics of feeder operations on the algorithmic design for the scheduling problem are as follows.

1. *Bobtails for vicinity loads*. Carriers run the same type of sorts in the same time periods across all the same type of facilities. Furthermore, loads can only be hauled in between sorts. Thus, it is preferable for loads to be hauled by bobtail-in or bobtail-out drivers than dispatching additional home base drivers. As an example, in Figure 2, a center 1 home base driver hauls center-1-L-to-hub-N load to hub, then bobtails to center 2 for center-2-L-to-hub-N, is a preferable scheduling scheme than dispatching an additional driver based in center 2. The latter dispatching method will create two under-utilized schedules.

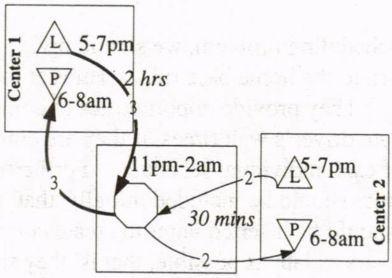

Figure 2: An illustrative trailer movement network

2. *Coupling center local outbound and preload inbound loads, which means centers are preferable driver bases*. Loads are originated at center local sorts that are re-handled at a hub sort, night sort in most cases, before destined to center preload sorts. To meet the rule of daily return to driver's home base, it is preferable to assign a center local outbound (to hub) load and an inbound to center preload (from hub) load in a single schedule. This means to begin drivers no earlier than the end of center local sorts, haul loads to hub, wait for return loads, and finish their daily schedules at where they start.

3. *Late start but early complete*. Start drivers as late as possible, but finish their schedules at when loads arrive. As an example again in Figure 2, we should not schedule a center 1 home base driver at 7pm, the earliest available time of center-1-L-to-hub-N load. The driver should start no earlier than 8pm. This time allows driver to meet its latest arrival time. In addition, it is sufficient for he to bobtail to center 2 for center-2-L-to-hub-N load. He will then take a break while waiting for return loads. If necessary, he will haul hub-N-to-center-P load, bobtail back for hub-N-to-center-P load. The driver should be scheduled to finish his daily work at 5am, at the moment of load arrives.

4. *Use an intermediate location, especially a hub, as a relay location*. Whenever a relay is necessary, the intermediate location of load origin and destination is a good candidate. Exchanging loads at such a location requires no additional detour runs. If possible, two drivers may meet for load exchange. This reduces the unnecessary bobtail by either one of the drivers. Furthermore, a hub is preferable than a center. As stated in strategy (3), a center is a preferable home base for drivers. Moreover, the inbound must equal to the outbound trailers for all the facilities. The high concentration of loads to hub for consolidation implies one of the drivers may pull one segment of loaded relay to hub or haul back the other segment from hub. As the result, no additional drivers are added. If the relay is for empties, there is an additional advantage of eliminating of driver's wait times. That is, we may start a driver at hub hauling one segment of the empty relay to center with a return of center local-sort outbound load. Similarly, another driver may haul

center preload-sort inbound load to center with a return of the other segment of empty relay to hub.

5. *Generate schedule patterns and solve integrality.* Since there are multiple loads over the same feeder segments, thus, we should generate schedule patterns and assign integer number of drivers to haul the demands. As an example, we should generate a schedule pattern of two load segments, center-1-L-to-hub-N departing at 9pm and hub-N-to-center-1-P arriving at 4am. If necessary, the driver can take a break at hub while waiting the return loads.

In summary, in the feeder scheduling problem, we should divide relay loads/empties into segments to ensure the return to the home base rule. Hubs at the intermediate locations are preferable exchange points. They provide opportunities to combine forward or return loads. In addition, we may eliminate driver's wait times, if they are empties. We should generate schedule patterns instead of each individual schedule. Furthermore, none of loads or empties to or from the vicinity should be included initially, that is, in the generation of *raw schedule patterns*. They should be inserted latter to create *complete schedule patterns*. Lastly, we will dispatch drivers as late as possible, that is, they should leave only when there is sufficient travel time for loads to arrive at the latest arrival times.

3. MATHEMATICAL MODEL

The feeder scheduling problem is formulated as an integer program. Denote P is a set of feeder schedule patterns. Their generation will be discussed in the following section. Furthermore, denote $\hat{T}$ as the *driver daily duty hour*. It is the maximum regular driving hours specified on the master union contract.

$$\min z = \sum_p C^p h^p \qquad (1)$$

subject to:

$$\sum_p \delta_{ij}^p h^p \geq \hat{L}_{ij}; \qquad ij \in \hat{A} \qquad (2)$$

$$t^p h^p \leq \hat{T}; \qquad p \in P \qquad (3)$$

$$h^p \geq 0, \text{int}; \qquad p \in P \qquad (4)$$

where the decision variable:

$h^p \geq 0, \text{int}$, the number of schedule pattern p.

and the parameters:

C^p: a coefficient that states the number of weekly driver for schedule pattern p. As an example, we need 1.5 10.5-hour 4-day or 1.2 8.4-hour 5-day a week drivers to cover a six-day weekly operation.

t^p: the total duty hour for schedule pattern p.

δ_{ij}^p: an element of the schedule pattern and link incident matrix; $\delta_{ij}^p = 1$, if link (i,j) on schedule pattern p; $\delta_{ij}^p = 0$, otherwise.

$\hat{L}_{ij}$: the planned number of loads and/or empties on link (i,j).

The objective function is to minimize the total number of weekly feeder drivers for the exogenous input loads and empties. The solutions to the scheduling problem do not alternate trailer equipment assigned to loads or empties, thus, their fixed costs are exclusive in the objective function. Since we do not consider overtimes, the problem is equivalent to a minimum cost assignment. Constraint (2) states that there must have sufficient schedule patterns to haul planned loaded and empty trailer movements. Constraint (3) states that the total time required by any schedule patterns cannot exceed the driver daily duty hour. The number of each schedule pattern is a nonnegative integer that is stated in constraint (4).

4. SOLUTION ALGORITHMIC DESIGN

We developed a heuristic approach for feeder scheduling problem. The algorithm consists of three modules, raw schedule pattern construction, schedule pattern evaluation and complete schedule pattern construction. The detailed procedure is described as follows.

Step 1 (**Load relay**). Whenever $t_{ij} > \hat{T}/2$, the non-stop travel time of a load is greater than a half of regular duty hour, designate a facility *k*, called *driver exchange point*, nearest to the intermediate point of *i* and *j*. Load segments (i,k) and (k,j) constitute the original non-stop load (i,j). Update set $\hat{L}_{ij} = \hat{L}_{ij} - \{(i,j)\} + \{(i,k),(k,j)\}$.

Step 2 (**Excess time**). For each load, the earliest departure (d) and latest arrival (a) times are sort end time of origin sort *i* and sort start time of destination sort *j*, respectively. Excess time (ET) with respect to load (i,j) is determined as $T_{ij}^{s} = T_{ij}^{a} - t_{ij} - T_{ij}^{d}$, for all (i,j).

Step 3 (**Load classification**). Loads are classified as *cold*, if they can be matched with and pulled by one of the *longer* travel time loads. That is, if $T_{ij}^{s} \geq 2t_{kl}$ and $T_{kl}^{a} \geq T_{ij}^{d} + t_{ij} + 2t_{kl}$, (k,l) is a cold load. In order words, waiting for drivers based in other facilities won't jeopardize their actual latest arrival times. Otherwise, they are *hot* loads. As an example, in Figure 2, a driver should be dispatched at center 1 hauling center-1-L-to-hub-A-N, and bobtail to center 2 for center-2-L-to-hub-A-N load. In this case, the former is hot, while the latter is cold.

To implement, we sequence loads in a descending order of ET. We iteratively select a pair of two consecutive loads, (i,j) and (k,l). If $T_{ij}^{s} < 2t_{kl}$, (i,j) is classified as a hot load, and becomes an element of H, $H = H \cup \{i,j\}$. When completion of the list, we ensure that all the cold loads will be eventually matched with available hot loads. The procedure is to insert the first cold to the first hot load, and in the meantime subtract round trip travel time from the ET of the hot load. That is, $T_{ij}^{s} \leftarrow T_{ij}^{s} - 2t_{kl}$. When infeasible, we select the next available hot load. However, whenever some of cold loads can not be matched at the end, we update the first cold as a hold load. Repeat the procedure until all the cold can be matched by at least one of the hot loads.

Step 4 (**Raw schedule construction**). We complete enumerate all possible schedule patterns for all the hot loads. This completes the set of raw schedule patterns.

Step 5 (**Raw schedule evaluation**). With all the possible raw schedule patterns, we solve the

IP problem of (1)-(4). In this research, we used a commercial IP package, Cplex for our numerical testing.

Step 6 (**Complete schedule construction**). Again, we sequence the raw schedule patterns selected by step 5 and sequence them in a descending order by ET. In addition, we sequence the cold loads in descending order by their travel times. We insert as many as cold loads into each schedule pattern in sequence until it is infeasible.

5. COMPUTATIONAL RESULTS

In this research, we used a partial and complete line-haul operations network of the third largest freight delivery common carrier in Taiwan for numerical testing. The carrier is under the plan to reconfigure the top three centers to be fully mechanical hubs. They are Taipei, Taichung, and Yungkang. Thus, we selected the top ten centers along with those 3 hubs, as shown in Figure 3, to form our partial network. The global and local optimal solutions are organized in Table 1.

Table 1: computational results for 3-hub and 10-center line-haul operations network

Schedule pattern	# drivers (hours)	Schedule pattern	# drivers (hours)
Same schedule pattern for both exact and heuristic approaches			
Fengshan→Taichung→Fengshan	3 (10.40)	Chiayi→Taichung→Chiayi	3 (6.96)
Sungshan→Taichung→Sungshan	2 (10.14)	Chiayi→Yungkang→Chiayi	1 (5.44)
Banchiau→Taichung→Banchiau	2(9.8)	Kaohsiung→Taichung→Kaohsiung	4 (9.04)
Dali→*Taipei*→*Banchiau*→Taipei→*Banchiau*→*Taipei*→Dali	1 (10.44)	Hsinchu→*Taichung*→*Fengyuan*→Taichung→*Fengyuan*→*Taichung*→Hsinchu	2 (8.00)
Fengyuan→Yungkang→Fengyuan	1 (9.08)	Taichung→*Chungli*→*Taichung*	1 (4.92)
Dali→Yungkang→Dali	2 (8.64)	Yungkang→*Taichung*→*Yungkang*	1 (5.40)
Tauyuan→*Taichung*→*Dali*→Taichung→*Dali*→*Taichung*→Tauyuan	3 (9.16)	Fengyuan→*Taipei*→*Banchiau*→*Taipei*→*Banchiau*→Taipei→*Banchiau*→*Taipei*→*Banchiau*→*Taipei*→Fengyuan	1 (10.32)
Chungli→Taichung→Chungli	3 (7.92)		
Different schedule patterns			
Heuristic approach		**Exact approach**	
Hsinchu→*Taipei*→*Tauyuan*→Taipei→*Tauyuan*→*Taipei*→Hsinchu	3 (8.16)	Hsinchu→*Taipei*→*Tauyuan*→*Taipei*→*Tauyuan*→Taipei→*Tauyuan*→*Taipei*→*Tauyuan*→*Taipei*→Hsinchu	1 (10.40)
Kaohsiung→*Yungkang*→*Fengshan*→Yungkang→*Fengshan*→*Yungkang*→Kaohsiung	4 (8.84)	Hsinchu→*Taipei*→*Sungshan*→*Taipei*→*Sungshan*→Taipei→*Sungshan*→*Taipei*→*Sungshan*→*Taipei*→Hsinchu	1 (9.04)
Chungli→*Taipei*→*Sungshan*→Taipei→*Sungshan*→*Taipei*→Chungli	3 (5.97)	Chungli→*Taipei*→*Chungli*→*Taipei*→*Chungli*→Taipei→*Chungli*→*Taipei*→*Chungli*→*Taipei*→Chungli	1 (9.9)
		Fengshan→*Yungkang*→*Fengshan*→Yungkang→*Fengshan*→*Yungkang*→Fengshan	1 (9.00)
		Sungshan→*Taipei*→*Hisnchu*→Taipei→*Hsinchu*→*Taipei*→Sungshan	1 (9.62)
		Kaohsiung→*Yungkang*→*Kaohsiung*→Yungkang→*Kaohsiung*→*Yungkang*→Kaohsiung	2 (8.76)

Note: Bobtails are in italic; empty trailer movements are underlined.

To determine the global optimal solution, we generated 119 all possible schedule patterns with a complete 157 load and empty segments. It took only 1.28 seconds by Cplex to determine the optimal solution with 11 of 8.4 hours and 26 of 10.5 hours schedule patterns. The former requires 1.2 drivers weekly, while the latter requires 1.5. Thus, the carrier requires 52.2 drivers to cover a week of operations. The utilization is the driver total driving hours divided by their pay hours. As the result, the utilization is 88.24% with 82.68% for 5-day drivers and 90.59% for 4-day drivers.

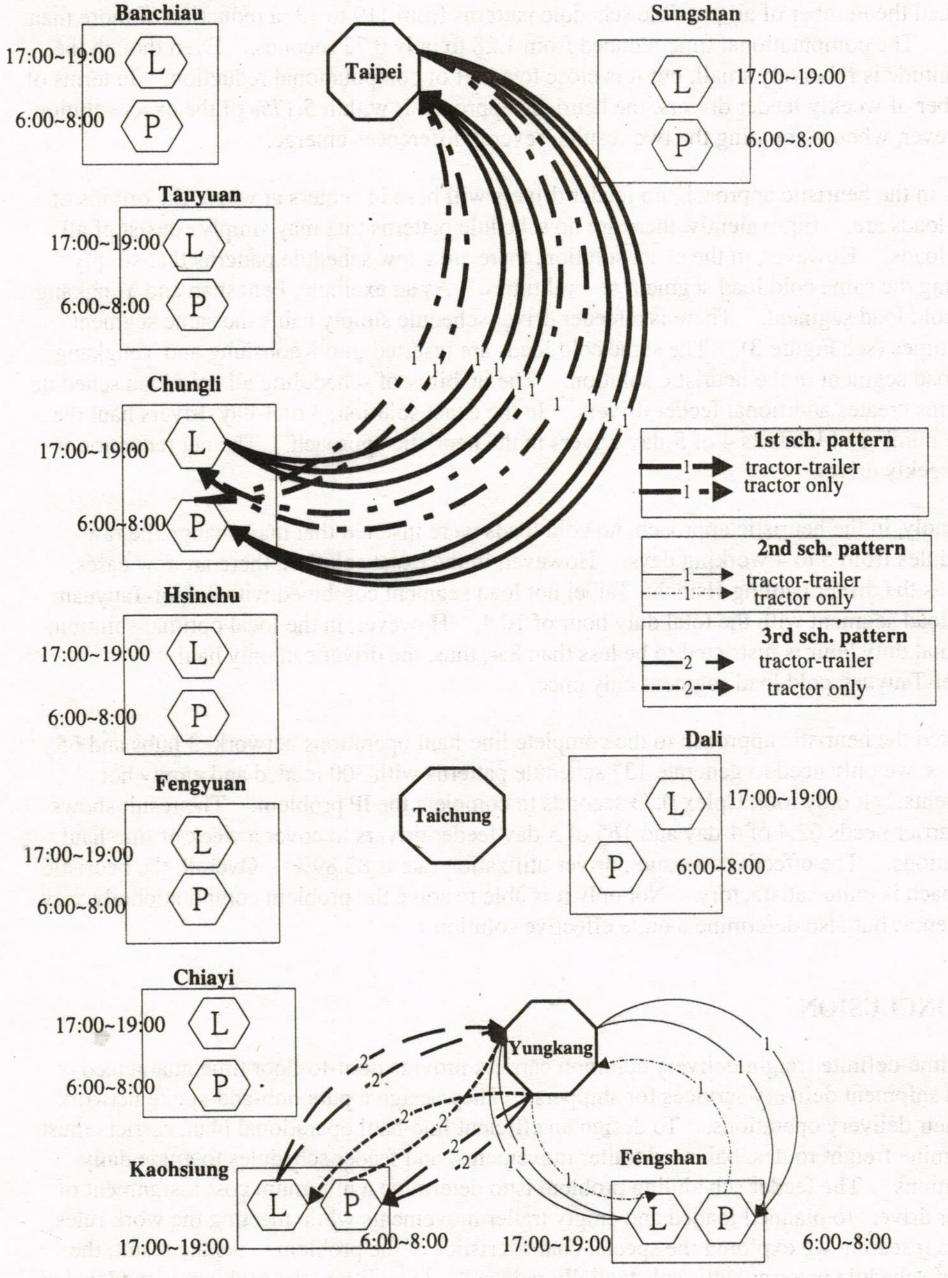

Figure 3: A partial exact solution for 3-hub and 10-center network

The heuristic approach reduced the size of IP problem to 13 raw schedule patterns for 39 hot loaded and empty segments. It took Cplex 0.72 seconds to determine the optimal IP solution. Upon completion of inserting cold loads, the plan calls for 17 of 8.4 hours drivers with 83.18% utilization, with additional of 23 of 10.5 hours drivers with 89.94% utilization. The total utilization is 87.08% for a crew of 54.9 drivers to cover a week of line-haul operations.

The computational results for a small network are encouraging. The heuristic approach has reduced the number of all possible schedule patterns from 119 to 13, a reduction of more than 85%. The computational time reduced from 1.28 to only 0.72 seconds. Even though the magnitude is relatively small, but it is close to a half of computational reduction. In terms of number of weekly feeder drivers, the heuristic approach is within 5.17% of the exact solution. However, when comparing the two results, several differences emerge.

First, in the heuristic approach, no feeder drivers will base in centers at where the origins of cold loads are. Equivalently, there are no schedule patterns that may simply consist of all cold loads. However, in the exact solution, there are a few schedule patterns that simply hauling the same cold load segment several times. As an example, Fengshan and Yungkang is a cold load segment. There is a feeder driver schedule simply hauls the same segment four times (see Figure 3). The same cold loads are inserted into Kaohsiung and Yungkang hot load segment in the heuristic solution. The inability of scheduling all cold load schedule patterns creates additional feeder drivers. In the exact solution, 3 of 4-day drivers haul the same number of loads as 4 of 5-day drivers in the heuristic approach. The net reduction is 0.3 weekly driver.

Secondly, in the heuristic approach, no cold loads were inserted that may change the raw schedules from 5 to 4 working days. However, in the exact solution, there are few cases, such as the driver hauling Hsinchu-Taipei hot load segment combined with Taipei-Tauyuan cold load segment with the total duty hour of 10.4. However, in the local optimal solution, the total duty hour is restricted to be less than 8.4, thus, the driver can only haul Taipei-Tauyuan cold load segment only once.

Applied the heuristic approach to the complete line-haul operations network, 3 hubs and 65 centers, we only need to generate 137 schedule patterns with 300 loaded and empty hot segments. It only took Cplex 0.73 seconds to complete the IP problem. The result shows the carrier needs 62.4 of 4-day and 165 of 5-day feeder drivers to cover a week of line-haul operations. The effective measure, driver utilization rate is 83.89%. Overall, the heuristic approach is quite satisfactory. Not only it is able to solve the problem computationally very efficiency, but also determine a quite effective solution.

6. CONCLUSION

The time-definite freight delivery common carriers provide door-to-door time guaranteed small shipment delivery services for shippers. They design a pure hub-and-spoke network for their delivery operations. To design an efficient line-haul operational plan, carriers must determine freight routes, balanced trailer movements, and feeder schedules to guide daily operations. The feeder scheduling problem is to determine a minimum cost assignment of feeder drivers to planned loaded and empty trailer movements while meeting the work rules. In this research, we explored the special characteristics of the problem. As the result, the size of schedule patterns set is substantially reduced. In addition, the problem is modeled as an integer program instead of classical set partitioning problem. We used the operations network of the third largest common carrier in Taiwan with randomly generated demands for numerical testing. The approach is capable to solve the line-haul operations network in Taiwan in a very efficient computational time and results in an effective solution.. It demonstrates the approach is capable for practical implementation.

However, there are several extensions. To combine hot and cold loads to generate complete schedule patterns, in effect, is a knapsack problem. That is, it is to determine the least number of feeder schedule patterns to haul all the loads and empties while meeting driver work rules. Loads are objects, while driver duty hour is the size of boxes. It is to assign loads (object) to duty hour (box) so that the least number of feeder schedule patterns (boxes) is determined (used). A more elegant approach should be considered in the future research. Furthermore, in the generation of complete schedule patterns, we should not limit to bundling hot and cold load segments together, but should also consider schedule patterns with all cold load segments, as the numerical testing has shown.

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