A Study on Transportation Planning Design with Practical Case Studies Based on Mathematical Models

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This research aims to design the optimal transportation routes/planning for two case studies which are the product delivery planning of one logistics company in Thailand and the container transportation of Japanese domestic demand. Two mixed integer programming models were individually formulated based on real transportation circumstances of each case and Xpress-MP® was employed to search for the optimal solution. From the results, this approach achieved better transportation planning with lower cost than current situation of the company in first case. For the second case, ship routes and ship types with minimum CO_2 emission can be obtained. Finally, the simulation results showed that CO_2 can be reduced by reducing the customs time at hub port.
Key words: Cost minimization, reduction of CO_2 emission, VRP, VRPPD, MIP model, Xpress-MP

1 Introduction

Route planning is an important task in transportation planning design. Optimal route planning help reducing not only the logistics cost but also the CO_2 emission. This research aims to solve two real-life practical problems based on each transportation conditions by using operations research. The objective is to minimize transportation cost in the first problem while it is to reduce CO_2 emission in the second problem. Apart from solving problems, this research also pointed out some limitations of the approaches.

2 Vehicle routing problem

Vehicle routing problem (VRP) has been widely studied in these recent decades. For the first problem, its nature belongs to the heterogeneous fleet vehicle routing problem (HVRP). Golden et al [1] were among the first to address this problem. They proposed the mathematical formulation, several saving heuristics and also created standard instances for HVRP. On the other hand, the second problem belongs to the vehicle routing with pickup and delivery (VRPPD). Nagy and Salhi [2] proposed some heuristics algorithms for single and multiple depot vehicle routing problems with pickups and deliveries.

3 Truck routing design for product delivery planning

3.1 Problem definition

The problem is to decide truck routes and truck fleet in order to transport products to all customers as shown in Fig. 1 with minimum total cost *(TC)*. *TC* is calculated by equation (1) where FC_j, VC_j and d_j are fixed, variable cost and distance from depot to destination of truck j, respectively. FC_j and VC_j depend on truck type while d_j depend on quality of route/planning. The problem is restricted by three constraints: truck volume capacity, maximum number of shop to deliver and route constraint. Route constraint means truck must be assigned to only one main route. There are two types of vehicle and each type has multiple vehicles. Finally, the shipments have to be arranged within fifteen minutes.

$$TC = \sum_{j \in Trucks} FC_j + \sum_{j \in Trucks} VC_j \cdot d_j \qquad (1)$$

3.2 Mathematical model formulation

As an approach to solve the problem, MIP model was developed with the objective function of minimizing total cost subject to three main constraints mentioned above. The decision variable for assigning truck to customer is restricted to be binary variable. Then Xpress-MP was employed as an optimization tool to search for the optimal solution by branch-and-bound method.

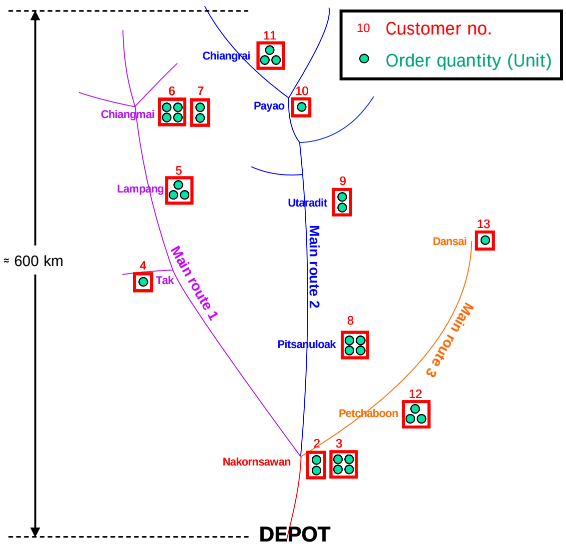

Fig. 1 Customers locations and route map

3.3 Heuristics based on Push Forward Insertion Heuristics (PFIH)

Three algorithms based on PFIH: PFIH1, PFIH2, and PFIH3 were developed. All of them start new route by selecting initial customer and then inserting customers into current route until capacity of vehicle is exceeded. The processes will be iterated until all customers have been routed like shown in Fig. 2. In the selecting initial customer step, for PFIH1, T_1 is the products quantity ordered by customer, and for PFIH2, T_2 is the distance from the distribution center to customer. Finally for PFIH3, T_3 as shown in equation (2) used the combination between T_1 and T_2 on various sets (static and dynamic) of weight factors.

$$T_3 = \alpha \cdot T_1 + \beta \cdot T_2 \qquad (2)$$

1. Begin with an empty route starting from the depot
2. If {all customers have been routed} then
   - ■ Go to step 9

   For all unrouted customers j: compute T according PFIH1 and PFIH2
3. Select the first customer, j*, with the maximum T and feasible in terms of all specified constraints
4. Append j* to the current route and update the capacity of the route
5. For all unrouted customers compute the distance from the nearest routed customer
6. Select an unrouted customer j* that has the maximum T
7. If {insertion of customer j* is feasible in terms of capacity and all other constraints} then
   - ■ Insert customer j* into the current route
   - ■ Update the capacity of current route r, and
   - ■ Go to step 5,

   Else
   - ■ Go to step 8
8. Begin a new route from depot
   - ■ Set r = r+1
   - ■ Go to step 2
9. All customers have been routed
   - ■ Stop with a PFIH solution

Fig. 2 Pseudo code of PFIH

3.4 Computational results

We tested our formulated MIP model, PFIH1, PFIH2, and PFIH3 on the real data of the company on September 6, 2004. There are 34 orders to be delivered. A computer with Intel® Core™ 2 CPU, T7200 @ 2.00 GHz 2.00 GHz, 1.50 GB of RAM was used for execution. The results are shown in Table 1.

The result from 15 minutes run-time on Xpress-MP is better than the solution by company officers in terms of computational time and total transportation cost. All PFIH spent less than one second for calculation. Shipments arranged by PFIH2 and PFIH3 yielded lower cost than those from officers.

Table 1 Computational results summary

Method	*Computational time*	*Used trucks*		*Total cost*	*Cost index*
		Amount	*Type*	*(Baht)*	
CTL officers	15 minutes	10	1L 9S	48,118	100.0
Xpress-MP	15 minutes*	7	4L 3S	40,578	84.3
PFIH1	Less than 1 sec	8	6L 2S	53,584	111.4
PFIH2	Less than 1 sec	9	4L 5S	47,576	98.9
PFIH3	Less than 1 sec	9	4L 5S	46,085	95.8

*The result from Xpress-MP shown here is not the optimal solution, but the best solution found so far from fifteen minutes run-time.

3.5 Discussion and future direction

In the capacity constraint, 85% of truck capacity (based on officers' experience) is used instead of full truck load in order to avoid cases that products cannot be loaded into truck. However, the utilization of some shipments arranged by officers is less than 85% since they consider the real products arrangement inside truck. Therefore, future work is to add this consideration into model. Another limitation of these approaches is the less flexibility than those of officers. In order to achieve best shipments, the combination between these presented approaches and opinion from expert officers is recommended.

4 Ship routing design for Japanese domestic container transportation

4.1 Problem Definition

In this problem, Kobe port is considered as a hub port. There is a huge amount of containers imported from foreign countries being loaded down here. A certain amount of containers have to be delivered to each feeder port, and at the same time, some containers need to be picked up from the feeder port and sent back to the hub port. The aim is to find the optimal set of ship routes and ship fleets with the least carbon dioxide emission which satisfies all customer demands with respect to the capacity constraint and maximum ship traveling time constraint.

4.2 Data of container transportation demand

The demand data was accumulated from the “Survey on Port and Harbor” website. It was an average weekly demand data in 2003. There are 21 ports including hub port with different delivery, pickup demand, and port loading/unloading speed. Four domestic container ships with different capacity, speed, and engine power were selected as vehicles.

4.3 CO_2 emission calculation

Equation (3) showed the CO_2 emission calculation. Constant *FCR*, ρ and *ER* are fuel consumption rate, density of crude oil, and CO_2 emission ratio, respectively. Three variables: *HP*, *v* and *Dist* are the horsepower, ship velocity and traveled distance. *HP* and *v* vary to types of ship while *Dist* depends on the quality of routes planning.

$$CO_2 = \frac{FCR}{\rho} \cdot (Avg.NOR/MCR) \cdot HP \cdot \frac{Dist}{v} \cdot ER \quad (3)$$

4.4 Route time calculation

Equation (4) showed the route time (*RT*) calculation. D_i, P_i, PS_i and MT_i are delivery, pickup demand, port speed and miscellaneous time at port *i*, respectively.

$$RT = \sum_{i,j \in Route} \frac{Dist_{ij}}{v} + \sum_{i \in Route} \left(\frac{D_i + P_i}{PS_i} + MT_i \right) \quad (4)$$

4.5 Mathematical models formulation

The models are divided into two phases: *route construction phase* (phase 1) and *route combination phase* (phase 2). Phase 1 creates individual ship routes with the least carbon dioxide emission in total while phase 2 combines the individual ship routes from phase 1 and assigns the combined routes to ships by not violating the maximum traveling time of ship. The objective of phase 1 is to minimize the CO_2 emission while phase 2 is to minimize the number of required ships.

4.6 System validation testing

The model was tested on the VRPPD instance of Gribkovskia et al [3] which has 14 nodes including depot. Three vehicle capacity cases: unlimited, 300, and 150 unit were tested. In the first case, the solution from this approach is the same as those of Gribkovskia. However in the second and third cases, this approach yielded better solutions with lower cost. This test proved that this approach can provide good solutions by not violating the capacity constraint.

4.7 Ship route results (phase 1 and phase 2)

The results by employing four types of

ships were compared in terms of CO_2 emission, total traveled distance, number of required routes, and number of required ship as shown in Table 2. Ship number 2 yielded the best result with minimum CO_2 emission.

Table 2 Results summary from four types of ships

Key indicators	*Ship type*			
	1	*2*	*3*	*4*
Capacity (TEU)	250	250	140	140
Speed (Knot)	14.5	12.0	16.8	14.0
Horsepower (PS)	2,800	2,200	3,500	2,000
CO_2 emission (ton)	351.45	333.42	535.84	371.35
Distance (NM)	5,380	5,376	7,603	7,684
No. of routes	13	13	21	21
No. of ships	5	5	5	6

4.8 Results and maximum traveling time

At hub port, goods imported from foreign countries must wait for customs process before they can be shipped. Four scenarios with different customs process time: 0, 1, 2, and 3 days were tested on two types of ships which yielded the minimum CO_2 emission in 4.7. The results summary is shown in Table 3. Note that there is no feasible solution for ship type 1 in scenario 4, and for ship type 2 in scenarios 3, 4 because ships cannot complete some routes in those scenarios.

Table 3 Routes results summary of four scenarios

Key indicators	*Ship type*				
	1			2	
Scenarios	1	2	3	1	2
Waiting time (day)	0	1	2	0	1
CO_2 emissions (ton)	351.45	354.7	379.2-	333.42	349.8
Distance (NM)	5,380	5,430	5,805	5,376	5,640
No. of routes	13	13	14-	13	13
No. of ships	5	5	7	5	5

4.9 Discussion and future direction

Based on the simulation results, there are two discussions: 1) big-sized ship with low engine power tends to give good result with low CO_2 emission despite its low speed; 2) waiting time for customs process at hub port has reverse proportional relationship with CO_2 emission. Future direction should focus on the combination between all types of ships and adding multiple time windows at ports including consideration of split deliveries.

5 Conclusion

In this thesis, the use of mathematical modeling approach for transportation planning design were presented and implemented to solve two practical problems. MIP models were individually developed based on real conditions in each problem and solved on Xpress-MP. In the first problem, heuristics were also developed. The results from all approaches were compared with those from company expert officers. Our approaches yielded better results and showed high potential to be better ways for product delivery planning at this company. In the second problem, another model was tested on four types of container ships with different capacity, speed, and main engine horsepower. The optimal routes for each ship type with minimum CO_2 emission can be obtained. Finally, the CO_2 emission can be reduced by reducing the customs process time at hub port.

6 References

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