

A Feasibility Study for Joint Services of Vehicle Routing and Patrol

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Abstract

The patrol and security companies in Taiwan develop a new way of survival using their patrol capability. A preliminary study in this paper is to combine the traditional service of vehicle routing delivery in a regular patrol and security routings. A mathematical model is first developed for these joint routing services. The objective of this model is to minimize the number of vehicle as well as the traveling cost. A heuristic algorithm using the simulated annealing algorithm is also developed for solving the problem. The effectiveness of this proposed model and the profitability of the proposed solutions are tested through several numerical examples.

Keywords: *Vehicle Routing Problem, Patrol and Security Service, Simulated Annealing Algorithm.*

1. Introduction

The security organizations in Taiwan are facing competitions not only on traditional security tasks but also on the capability of logistics. Since the market for the security industry is nearly saturated, it is a good strategy to combine the delivery service in the security service. The trade-off of this decision is the motivation of this research.

This research will focus on the model development and solution algorithm. The cost comparisons include three different models: (1) the traditional vehicle routing model, (2) the original security service model, and (3) the combined security-vehicle routing model. Basically, if the cost of model (3) is less than the sum of model (1) and model (2), it will be convinced that the combined security-vehicle routing model is profitable and the detailed operational procedure of security-vehicle routing service is worth of further investigation.

The security operation discussed in this paper focuses on the tasks of daily patrol routine. The logistic distribution operation is concentrated on one-way delivering goods from distribution center to customers. Therefore, the security-vehicle routing model will combine the patrol tasks and the tasks of delivering goods in each vehicle route. The difference between the traditional vehicle routing and the security-vehicle routing model is the emergency service occurred unexpectedly during the daily patrol routine. In this research, we use several probabilities to represent the emergency service happened during the daily security service.

Several meta-heuristics are suggested for solving the traditional vehicle routing problem, such

as tabu search, simulated annealing algorithm, genetic algorithm, noising method, threshold accepting method. The solution algorithm developed in this paper applies the concept of simulated annealing algorithm (Chiang and Russell, 1996). In addition, the Taguchi experiment design is also used to decide the near optimal parameters of simulated annealing algorithm.

2. Model Development

2.1 Problem statement and assumptions

The basic idea of this research is to investigate the distance cost for the security-vehicle routing model. In a regular security routine service, there are three important features: districting area, responsibility, and emergency service (Calvo and Cordone, 2003). This combined security-vehicle routing model will consider the first two features by using the concept of time window which is the same as a traditional vehicle routing problem. Each vehicle is responsible for each service routing when the security tasks added into a vehicle transportation service. The security service area will also cover the customers of distribution service area. In this study, the representation of an emergency service is solved by using a probability to represent the requirement for emergency service. Once the patrol service and delivery service is interrupted by an emergency call, the vehicle will be re-routed to the emergency case temporarily. This extra cost will also be considered in the security-vehicle routing model. The following assumptions will further describe the security-vehicle routing model in details.

- (a) There are only two types of customers which come from security service and goods transportation. No overlapping customer exists in this study. Locations of customs are fixed, known, and given.
- (b) In each service route, the vehicle starts from the distribution center (same as the security service center or the patrol service center) and the route will end at the same point. During one service route, security service or delivery service will be executed for customers depending on their types.
- (c) All vehicles have the same loading capacity and no over loading is acceptable in any segment of route.
- (d) In a service route, each patrol point has a given and fixed probability for requirement of the emergency service. After the emergency service, the vehicle will go back to the interrupted point and continue the following service routing.
- (e) Only the drop-off delivery operations are considered and no pick-up operations are considered in this study. The daily delivery quantity of each customer is fixed, known, and given.
- (f) A constant speed is assumed for each vehicle and the speed is known and given.

(g) A hard time window is assumed in the model and in the associated solution procedure.

2.2 The mathematical model and the associated constraints

Based on the problem statement and the basic assumptions indicated in section 2.1, a mathematical model is constructed in this subsection after the definitions of variables and parameters which are summarized as follows.

(1) Variables and parameters

N : number of patrol points and delivery points.

M : number of routing which is same as number of responsible area.

v : the set of active vehicle.

0: the starting/ending point which also represents the distribution center and security service center.

Q_v : loading capacity of vehicle v .

q_i : quantity required for delivery point i .

H : a set of the points that the emergency service is required.

N_a : a set of all patrol points.

N_L : a set of all delivery points.

W : a set of all patrol points and delivery points including the starting/ending point.

$$W \in \{N_a \cup N_L \cup 0\}$$

T_{ij} : travel time requirement from service point i to service point j . $T_{ij} \geq 0$.

P_i : time to start the service for service point i . (unknown)

S_i : service time for service point i . (fixed, given, and known)

F_j : the vehicle arrival time at the service point j . (unknown)

e_i : the lower limit of time window at the service point i . (fixed, given, and known)

l_i : the upper limit of time window at the service point i . (fixed, given, and known)

d_{ij} : distance cost from service point i to service point j

d_{ib} : distance cost from service point i to emergency service point b

$P(b)$: the probability for emergency service requirement at service point b , $b \in H$

(2) Decision variables

y_{iv} : if the service point (delivery point or patrol point) i served by vehicle v , then $y_{iv} = 1$.
Otherwise, $y_{iv} = 0$.

X_{ijv} : if the path segment from service point i to service point j served by vehicle v , then $X_{ijv} = 1$.
Otherwise, $X_{ijv} = 0$.

Z_{ibv} : if the emergency service point b occurred when the vehicle v arriving at service point i ,

then $Z_{ibv} = 1$. Otherwise, $Z_{ibv} = 0$.

(3) The combined model

The following security-vehicle routing model includes patrol service and delivery service in details.

$$\text{Minimize } \sum_{i \in W} \sum_{j \in W} \sum_{v=1}^M d_{ij} X_{ijv} + 2 \sum_{i \in W} \sum_{b \in H} \sum_{v=1}^M P(b) d_{ib} Z_{ibv} \quad (1)$$

Subject to:

$$\sum_{i \in W} \sum_{v=1}^M X_{ijv} = 1 \quad \forall j \in W \quad (2)$$

$$\sum_{j \in W} \sum_{v=1}^M X_{ijv} = 1 \quad \forall i \in W \quad (3)$$

$$\sum_{i=0}^N X_{iuv} - \sum_{j=0}^N X_{ujv} = 0 \quad v = 1, 2, \dots, M, \quad u \in W \quad (4)$$

$$\sum_{i \in W} \sum_{j \in W} q_i X_{ijv} \leq Q_v \quad v = 1, 2, \dots, M \quad (5)$$

$$\text{If } X_{ijv} = 1 \Rightarrow P_i + S_i + T_{ij} = F_j \quad \forall (i, j) \in W, v = 1, 2, \dots, M \quad (6)$$

$$e_i \leq P_i \leq l_i \quad \forall i \in W \quad (7)$$

$$\sum_{v=1}^M y_{iv} = 1 \quad \forall i \in W \quad (8)$$

$$\sum_{i \in W} y_{iv} = \sum_{i \in W} \sum_{j \in W} X_{ijv} \quad v = 1, 2, \dots, M \quad (9)$$

$$y_{iv} \in \{0, 1\} \quad \forall i \in W, v = 1, 2, \dots, M \quad (10)$$

$$X_{ijv} \in \{0, 1\} \quad \forall (i, j) \in W, v = 1, 2, \dots, M \quad (11)$$

$$Z_{ibv} \in \{0, 1\} \quad i \in W, b \in H, v = 1, 2, \dots, M \quad (12)$$

The objective function, i.e. the equation (1), is to minimize total distance cost including the patrol and delivery distance as well as the distance for emergency service. Equation (2) and (3) indicate that each route served by one vehicle only and each service point is served once, respectively. Equation (4) ensures that one vehicle arrives one service point and the same vehicle will leave this service point. Equation (5) indicates that the over loading capacity is unacceptable at any service point in any route. The hard time window is defined and represented in equation (6) and equation (7). For each service point, equation (8) and (9) restrict one and only one vehicle provides patrol and delivery service. Equation (10), (11), and (12) indicate the decision variables which are either 0 or 1.

3. Solution Algorithm

The solution algorithm developed in this section includes two phases. Phase one constructs

initial routings and improves the vehicle routings. Phase two will further consider the emergency service adding into the current vehicle routings. In the numerical examples illustrated in section 4, the proposed solution algorithm will apply in three different models for comparison purpose. The cost of traditional vehicle routing model, i.e. the model (1), is the delivery cost only. The cost of patrol service model, i.e. the model (2), includes the regular patrol cost and the emergency service cost. Consequently, the cost of combined security-vehicle routing model, i.e. the model (3), will include the regular delivery cost, the regular patrol cost, and the emergency service cost.

3.1 Phase one – Generate regular routings

The initial routing is started from the depot point (distribution center or security service center) and the following procedure is based on the concept of nearest neighbor heuristic. The nearest point of the current point will be included as the next visiting point. The procedure will repeat until the vehicle reaches the loading capacity or time window. The following routing is repeated until all service points are included in the routings.

In the improvement of vehicle routings, the simulated annealing is used as the basic searching logic including internal and external exchanges process. The detailed improvement procedure is presented as the following steps.

- Step 1. Initialize parameters for a simulated annealing procedure including the initial temperature, temperature of termination (TSTOP), cooling rate, and number of iteration at a given temperature (NOVER).
- Step 2. Generate the initial vehicle routings. Calculate value of objective function. Set the “current” optimal solution to be this objective function value.
- Step 3. If the current temperature reaches TSTOP, then stop the procedure.
- Step 4. Check the number that the “current” optimal solution has not been updated (i.e. K). If K reaches the pre-defined number (M), then stop the procedure.
- Step 5. Use 2-Opt logic to make an exchange (move). Exchanges includes 1-1 internal exchange, 1-1 external exchange, and 1-0 node insert.
- Step 6. If the new solution is better than the “current” optimal solution, then set the “current” optimal solution to be this new solution and set K=0. Otherwise, check the probability $P(\delta)$ to accept the new (worse) solution, as indicate in equation (13). If the worse solution is accepted, then update the “current” optimal solution and set K=0. Otherwise, set K=K+1.

$$P(\delta)=e^{\frac{-\delta}{T}} \quad (13)$$

Where: δ = (new solution) – (current optimal solution), T = current temperature.

Step 7. If the number of iteration at current temperature reaches NOVER, then reduce current temperature and go to step 3. Otherwise, go to step 4.

3.2 Phase two – Add the emergency services into routings

Phase one generates the cost of basic service for regular patrol points and regular delivery points. However, the cost of emergency service should be added in model (2) and model (3). The cost of emergency service is estimated by using a pre-defined probability $P(b)$ to generate the points that need an emergency service. Once the emergency service occurs, the current vehicle routing is interrupted and the vehicle will be re-routed to the patrol point that required an emergency service. After this emergency service, the vehicle will go back to the point which is interrupted and the vehicle re-starts the regular vehicle routing.

4. Numerical Examples

4.1 Illustration examples

Three models, as indicated in section 1 and section 3, will be tested and illustrated in this section. Model (1) performs the regular delivery operations and each service point in this model requires a given delivery quantity with time window. Vehicles in model (1) have a given and fixed loading capacity. Model (2) performs the regular patrol service and emergency service with time window, therefore, the vehicles in model (2) do not consider loading capacity. Delivery service points in model (1) are different from patrol service points in model (2). Locations of all service points including model (1) and model (2) are fixed and known, which are randomly generated within a given area (i.e. a square of 1000×1000). Since service points in model (1) and model (2) are different, no overlapping point occurs in both models. For model (1) and model (2), five cases will be tested and evaluated, which include the following number of service points: 25, 50, 75, 100, and 150.

The model (3) performs the combined operations which includes the patrol service, the delivery service, and the emergency service. For comparison purpose, the service points in each case of model (3) are consist of all service points in both model (1) and model (2). Therefore, the numbers of service point for each case will be 50 (25+25), 100 (50+50), 150 (75+75), 200 (100+100), and 300 (150+150), respectively. In each case of model (3), 50% of the service points require regular patrol service and emergency service. The other 50% of the service points require delivery service. For all three models, the vehicle speed in these cases is fixed as a constant speed (i.e. 83.33) and the maximal service time for each route is 240 minutes. For the cases in model (2) and model (3), the

probability of emergency service requirement is 1/3 at the beginning.

4.2 Parameters used in simulated annealing algorithm

The proposed solution algorithm, as indicated in section 3.1, applies the logic of a simulated annealing procedure. The parameters in a simulated annealing include an initial temperature, stopping criteria (i.e. stopping temperature), cooling rate, and number of iteration at a given temperature. For better searching results, it is necessary to fine tune the set of parameters by using the Taguchi experiment especially for each model. After this experiment process, the near optimal sets of parameters are summarized in Table 1.

Table 1 Parameters Used in Simulated Annealing Algorithm

Parameters Models	Initial Temperature	Stopping Temperature	Cooling Rate	Number of Iteration at Temp
Model (1)	3000	10	0.95	200
Model (2)	2000	50	0.99	150
Model (3)	3000	100	0.99	150

4.3 Results and discussion

The numerical results of all cases for model (1), model (2), and model (3) are summarized in Table 2. For comparison purpose, the costs of model (1) and model (2) are summed together which represent the delivery operations and petrol operations performing independently. These costs are presented in the column A of Table 2. The costs of model (3) are the main concern in this study, which are presented in the column B of Table 2.

Table 2 Comparison of Distance Cost

Number of Service Points	Vehicle Capacity 200 (unit)		Percentage of Improvement: [(A-B)/A]%
	A Model (1)+Model (2)	B Model (3)	
50	9245.3	7421.9	19.7%
100	16723.3	12436.3	25.6%
150	19507.9	15694.8	19.5%
200	23890.7	23003.7	3.7%
300	31676.7	32076.4	-1.3%

Remark: The probability of emergency service is 1/3 for model (2) and model (3).

From Table 2, most of the cases (i.e. the case of 50, 100, 150, and 200 service points) indicate that the combined model is profitable since the distance cost of model (3) is less than those of model (1) plus model (2). However, the loading utilization of the vehicle in model (3) will less than

those in model (1). This draw back situation seems reasonable since only 50% of the operations in model (3) perform delivery operations.

Other important cost impact is the probability of emergency service. It is believed that a higher probability of emergency service tends to reduce the profitability of model (3). Table 3 and Table 4 illustrate the cost deviations using different probabilities, i.e. 1/6 and 2/3 respectively. By observing the cases of 200 and 300 service points in Table 4, it is found that a trade-off point must be investigated before introducing a profitable model (3).

Table 3 Cost Comparison for Emergency Probability: 1/6

	Probability of emergency service: 1/6					
Vehicle Capacity	100			200		
Number of Service Points	A Model (1) + Model (2)	B Model (3)	(A-B) Cost Deviation	C Model (1) + Model (2)	D Model (3)	(C-D) Cost Deviation
50	10512.1	8091.8	2420.3	9095.1	6778.3	2316.8
100	17134.9	11884.7	5250.2	16205.9	11665.8	4540.1
150	23548.1	19084.5	4463.6	18676.1	15470.7	3205.4
200	31948.4	22641.7	9306.7	23561.4	19968.4	3593.0
300	41091.8	33591.2	7500.6	30752.8	25206.1	5546.7

Table 4 Cost Comparison for Emergency Probability: 2/3

	Probability of emergency service: 2/3					
Vehicle Capacity	100			200		
Number of Service Points	A Model (1) + Model (2)	B Model (3)	(A-B) Cost Deviation	C Model (1) + Model (2)	D Model (3)	(C-D) Cost Deviation
50	11035.6	10855.5	180.1	9618.6	8369.3	1249.3
100	18713.5	15207.4	3506.1	17784.5	15224.8	2559.7
150	26973.7	24783.8	2189.9	22101.7	21110.9	990.8
200	34959.2	31332.4	3626.8	26572.2	29086.2	-2514
300	43563.8	44270.6	-706.8	33224.8	39028.5	-5803.7

5. Conclusion

This research is a type of preliminary study which provides the security and patrol companies in Taiwan one possibility of survival using their patrol and logistic capability. A mathematical model is developed for the vehicle routings service combined with patrol service. The objective of the proposed model is to minimize the distance cost. A solution algorithm using the simulated

annealing procedure is also suggested. As the illustration results, most of the numerical examples indicate that the proposed combined security-vehicle routing model is profitable, however, the probability of emergency service is the key point for a trade-off decision which is also worth of further investigation.

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