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A Constructive Heuristic for Police Patrol Routing Problems

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ABSTRACT

Police patrol routing problem (PPRP) attracts researchers' attention especially on artifitial inteligence. The challenge here is that a limited number of patrols cover a wide range of area that includes several hotspots. In this study, a new model for PPRP is proposed simulating the Solomon's benchmark for vehicle routing problem with time windows. This model can solve this problem by maximising the coverage of hotspots with frequencies of high priority locations while ensuring the feasibility of routes. Two constructive greedy heuristics are developed to generate the initial solution of the PPRP: highest priority greedy heuristic (HPGH) and nearest neighbour greedy heuristic (NNGH). Experimental results show that the simulated Solomon's benchmark is suitable to represent PPRP. In addition, results illustrate that NNGH is more efficient to construct feasible solution than HPGH.

Keywords: Greedy heuristic, Police patrol routing problem, Vehicle routing

INTRODUCTION

Designing good quality police patrolling is an important task for designing preventive strategies to tackle crimes. Random preventive patrolling (Weisburd, Mastrofski, Mcnally, Greenspan, & Willis, 2003), high visibility patrolling (Braga, 2001), and hotspot policing (Braga, 2001; Koper, 1995) are some of the strategies discussed in the literature.

Several methods have been proposed for designing police patrol routes. Reis, Melo, Coelho, and Furtado (2006) designed the patrol routes based on genetic algorithm, and tested this using a simulation of a constant number of criminals and police officers as agents 'patrolling' an open area. The solution was designed and tested in a simplified scenario and requires sub-stantial improvements before it can be applied to

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police operational planning. Chawathe (2007) modelled the patrolled road network as an edge-weighted graph, and organised hot-spot police patrol routes based on the importance of segments and topology of the road network. The resulting patrol patterns of this approach are deterministic, depending entirely on crime rate distribution and the topology of the road network, and might be predicted by offenders. Chen and Yum (2010) developed an algorithm for patrol route planning based on a cross entropy method. This method was developed for single patrol unit planning, and faces challenges when ex-tended to multiple-unit patrolling. Tsai et al. (2010) derived a strategy for police resource allocation based on modelling the interactions between po-lice and terrorists as an attacker-defender Stackelberg game. However, this method assumes that a player always predicts his opponent's behaviour and chooses the best response, and may have difficulty in generalising to large numbers of agents and multiple crime types.

In addition, police patrol is also modelled as multi-agent patrolling based on a variety of concepts, including a probabilistic ants algorithm (Fu & Ang Jr, 2009) and Bayesian strategy (Portugal & Rocha, 2013). However, these methods are not directly applicable to police patrol, because of the complex-ity of implementation and oversimplification of the patrolling environment (static environment, distance, etc) (Fu & Ang Jr, 2009). Moreover, the previous methods treated the patrolling targets as points or nodes without con-sidering the ravelling time to the nodes (Portugal & Rocha, 2013). In addition, they do not consider the hotspot locations distributed across the city. Therefore, designing a police patrol route that can meet the real-world requirements is vital.

To the best of our knowledge, there is no benchmark for PPRP that fully meets the requirements of many real-life situations, especially those of the police department in Malaysia. Therefore, this work presents a PPRP based on vehicle routing problem with time windows (VRPTW) (Cordeau, Desaulniers, Desrosiers, Solomon, & Soumis, 2001). The PPRP has simi-larities to the VRPTW (Garcia Potvin, & Rousseau, 1994; Garcia-Najera and Bullinaria, 2011) that consists of finding routes that serve all customers with minimum cost (read minimum travelling distance).

In investigating the feasibility of solving PPRP, two greedy heuristics are developed: nearest neighbour greedy heuristic (NNGH) and highest priority greedy heuristic (HPGH) to construct an initial solution that considers the problem constraints and obtain a feasible solution. In section 2, we formulate the PPRP by using VRPTW. In section 3, we describe the two constructive heuristics, NNGH and HPGH, followed by the results of simulation of PPRP in Section 4. The paper concludes in Section 5.

MATERIALS AND METHODS

To reflect the real-life situation of PPRP, a new model for PPRP is proposed. The proposed model simulates the Solomon's benchmark for vehicle routing problem with time windows. This model has to be designed carefully in order to present an applicable model for PPRP which is a highly constrained problem (Chawathe, 2007).

The VRPTW assumes that there is predefined number of customers that is geographically distributed. Each customer has demands and time to be served. A set of vehicles with specified capacity is also given. The objective here is to serve all customers within their time windows at a minimum traveling distance (Cordeau et al., 2001). So, the main components of VRPTW are as follows: vehicle, customer, time window, customer's demand and vehicle's capacity. In order to design the PPRP based on VRPTW, we consider the following aspects: vehicles represent a police patrols, customers represent hotspots, customer's time windows - potential crime period of hotspot, customer's service time - hotspot's stopping time and vehicle's capacity - the maximum duty time for each patrol per day. Customer's demand is irrelevant in PPRP, so it will be discarded. On the other hand, the hotspot priority will be added for each hotspot. The priorities of hotspots and the values of maximum duty time of patrols are obtained from the police department in Malaysia. The priorities of hotspots are divided into three levels: high, mid and low. Hotspot with high priority should be visited 3 times while hotspot with mid and low priority should be visited 2 and 1 time respectively. Thus, hotspots are defined not only with their location on the city, but also with the time they become "hot" and the priority level of each hotspot.

The PPRP solution consists of a set of duties (based on the number of available patrols). Each duty consists of a set of routes and each route includes the hotspots which are covered by the patrol of that duty (see Figure 1).

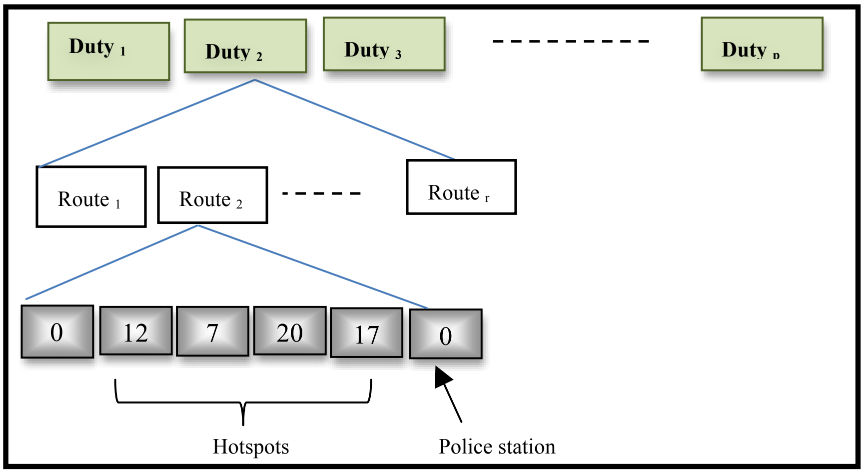

Figure 1. The representation of PPRP solution

Based on the abovementioned simulation, PPRP can be formulated as follows: we assume G (V,E) is an undirected graph, where V represents a set of hotspots V={0, 1, 2, …., n}, node 0 represents the police station and nodes 1, 2, 3, …, n represent hotspots. E is a set of edge E= {i, j:i≠j and i, j ∈ V} and each edge associated with travel time $t_{ij} = t_{ji}$ and $t_{ij} > 0$. Each hotspot has a potential crime period, beginning of period bi and ending of period e_i, and priority level which should be known in advance.

Based on a discussion with the police department in Malaysia, the stopping time of each hotspot is based on its priority, where the stopping time of high, mid and low priority hotspots are 10, 5 and 0 minutes respectively. Furthermore, the main role of PPRP is identified to maximise the coverage of hotspots while respecting the following constraints:

- Each hotspot should be visited within an imposed potential crime period.
- Each hotspot has a priority level, so the hotspot must be visited at least once or more based on its priority.
- Each patrol has a maximum route time, so the patrol should cover the desired number of hotspots and back to the station within a chosen period of time.
- There is a rest time (*RTime*) for each patrol after each route.
- Each patrol has a maximum duty time per day.
- Each route should start and end at the police station.

If the patrol arrives at the hotspot before the beginning of its potential crime period, the patrol has to wait until the potential crime period begins. The objective function of PPRP is calculated as follows:

$$Maximise\ f(S) = \sum_{p=1}^{P}\sum_{k=1}^{R}\sum_{i=1}^{n} a_i \cdot y_i^p .\ x_i^k \qquad (1)$$

$$y_i^p = \begin{cases} 1 & if\ hotspots\ i\ is\ covered\ by\ patrol\ p \\ 0 & Otherwise \end{cases}$$

$$x_i^k = \begin{cases} 1 & if\ hotspots\ i\ within\ route\ k \\ 0 & Otherwise \end{cases}$$

Where

- n: number of hotspot points
- P: number of patrols
- R: number of routes in each patrol
- a_i : the priority of hotspot i

The Proposed Method: Greedy Heuristic

Constructive heuristics are needed to construct an initial solution with an acceptable quality. Greedy heuristic (GH) is a very popular method used by many researchers as it is simple to design, effective and provides good initial solution. Greedy heuristic starts from an empty solution and constructs a solution by assigning elements to the empty solution based on their quality and feasibility, until a complete solution is generated (Talbi, 2009). In this work, two greedy heuristic are applied: nearest neighbour greedy heuristic (NNGH) and highest priority greedy heuristic (HPGH). Note here that the process of generating a solution using both NNGH and HPGH is the same and the only difference is the mechanism of selecting the hotspots. The ex-planation of both heuristic is given below.

Given a set of hotspots and police patrols, we first create an empty route. Then, a hotspot is randomly selected and inserted to the route. For NNGH, the nearest uncovered hotspot is added as long as it did not violate the problem constraints, and for HPGH, the hotspot with highest priority is selected and added to the route as long as did not violate the constraints. The process is repeated until no more hotspots can be inserted to the current route. The process of generating new routes and adding the uncovered hotspots is repeated until all hotspots have been covered. The qualities of all routes are then calculated using equation 2 and sorted in descending order based on the quality of each route. Hence, routes with higher cost (include more hotspots with high priority) have greater opportunity to be selected in the final solution than other routes. Afterward, the sorted routes are linked to form duties for patrols considering the maximum duty time per day. The best duties are then assigned to the available number of patrols. The basic steps of GH for PPRP are as follows:

Step 1: Create an empty route r and insert uncovered hotspots to the route until the maximum route time is exceeded.

Step 2: Repeat step 1 until all hotspots have been covered.

Step 3: Calculate the qualities of the generated routes based on the following equation:

$$f(r) = \sum_{i \in m} a_i$$

where m is the number of hotspots in the route r.

Step 4: Sort the generated routes in descending order based on their qualities, using Equation 2.

Step 5: for each patrol:

a. Create an empty duty and insert the best route to the duty, and then remove it from the list of routes.

b. Select the highest quality feasible route (r_h) and insert it to the duty if:

(Due time of $r_{last} + t_{L0} + RTime + t_{0F}) < e_F$

Where r_{last} is the last inserted route in the current duty, L is last hotspot in the r_{last} and F is the first hotspot in r_h

c. Remove route (r_h) from the route's list.

d. Repeat steps b and c until the maximum duty time is exceeded.

Step 5: Repeat step 5 until the duty of all patrols are generated.

RESULTS

The tested instances for PPRP were simulated from Solomon's VRPTW benchmark (Solomon, 1987). Four instances were simulated; each of them contained 50 hotspots and 5 patrols. Table 1 present the characteristics of these instances. Where HP, MP and LP refer to high priority, mid priority and low priority hotspots respectively. The information in Table 1 is determined based on our discussion with police department in Malaysia.

To investigate the effectiveness of the proposed constructive heuristics (HPGH and NNGH), the results which are obtained by these heuristics were tested on simulated instances, and compared with each other based on the quality of solutions. These heuristics have only one parameter, the termination condition of the search process. Both heuristics are terminated when a complete solution is generated, i.e., when all patrols have their duties. To evaluate the performance of these heuristics, 31 runs for each were performed.

Table 2 shows the results obtained by the NNGH and HPGH for PPRP. For each instance, the best results are indicated as (Best), average (Avr) and standard deviation (Std). As can be seen from Table 2, NNGH performed better than HPGH in three instances while HPGH performed better in one instance only. In particular, HPGH focus on the priority of the hotspot with-out considering the time of travelling from hotspot to another, which is time consuming and leads to less coverage of hotspots. To show the distribution of the solutions obtained by NNGH and HPGH, the box-whisker of solutions distribution are plotted (see Appendix A).

Table 3 contains the results of NNGH in detail. It covers all the hotspots over the four tested instances including the high, mid and low priority hotspots. Considering the high priority hotspots, 10 out of 11 hotspots were covered in instance police_R1, while all high priority hotspots were covered in instance police_R2. In terms of police_c1 and police_C2, 9 out of 10 were covered.

Table 1
The characteristics of the simulated PPRP dataset

Instance	HP-hotspots	MP-hotspots	LP-hotspots	No. of Patrols	Max route time(min)	Max duty time(min)	Rest time (min)	Hotspots' Distribution
police_R1	11	11	28	5	150	480	15	Random
police_R2	12	12	26	5	150	480	15	Random
police_C1	10	12	28	5	150	480	15	Cluster
police_C2	10	12	28	5	150	480	15	Cluster

Table 2
The results of both constructive heuristic NNGH and HPGHt

Instance	HPGH			NNGH		
	Best	Avr	Std	Best	Avr	Std
police_R1	61	50.68	4.69	81.00	67.74	6.35
police_R2	139	123.68	6.57	115.00	98.74	9.46
police_C1	80	62.00	8.41	97.00	82.29	5.97
police_C2	81	69.94	5.92	99.00	91.45	6.14

The results indicate the most covered hotspots were the hotspots with high priority. This is due to the join routes procedure when constructing the solution in which the route with high quality will have the highest chance to be selected and joined to the police patrol duty. As for total coverage of hotspots, instance police_R2 had the highest coverage in which 40 hotspots out of 50 were covered. These results are fair for the constructive heuristic method and also indicate that the simulated PPRP is valuable and applicable for representing the real world PPRP.

Table 3
The coverage hotspots using NNGH over the four tested instances

police_R1			police_R2			police_C1			police_C2		
High Hotspot/ NV	Mid Hotspot/ NV	Low Hotspot/ NV	High Hotspot/ NV	Mid Hotspot/ NV	Low Hotspot/ NV	High Hotspot/ NV	Mid Hotspot/ NV	Low Hotspot/ NV	High Hotspot/ NV	Mid Hotspot/ NV	Low Hotspot/ NV
29/2	28/1	34/1	31/2	10/2	16/1	40/2	49/2	50/1	5/3	10/2	45/1
4/3	23/2	41/1	40/1	35/2	26/1	29/3	44/1	30/1	15/2	7/1	21/1
40/3	25/2	2/1	49/1	28/2	2/1	17/3	23/1	18/1	31/2	12/1	27/1
49/1	1/2	33/1	42/3	23/1	19/1	31/2	10/2	8/1	17/3	23/1	6/1
31/1	12/1	22/1	37/2	44/2	48/1	37/2	20/2	33/1	4/1	9/1	3/1
17/2		47/1	38/1	25/2	39/1	42/1	28/1	34/1	42/3	35/1	43/1
37/1		48/1	17/3	20/1	14/1	4/2	9/2		40/2	25/1	8/1
42/2		24/1	32/3	7/1	41/1	5/2	1/1		37/2	28/1	41/1
38/2			4/3	12/2	13/1	15/2	35/2		38/2	26/1	32/1
5/2			15/2		3/1		7/2			20/1	47/1
			29/1		11/1		12/1			49/2	46/1
			5/1		6/1						13/1
					46/1						11/1
					45/1						
					34/1						
					27/1						
10	5	8	12	9	19	9	11	6	9	11	13
	23			40			26			33	

NV: number of visits

CONCLUSION

In this study, the police patrol routing problem was introduced by simulating the vehicle routing problem with time windows. The motivation for this simulation was to imitate the real world PPRP that aimed to maximise the coverage of important hotspot locations. Two greedy heuristic were also introduced: highest priority greedy heuristic and nearest neighbour greedy heuristic, in order to generate a feasible initial solution that considered the problem constraints. Experimental results showed that the proposed model was applicable to represent the PPRP. Moreover, results indicated that the NNGH was able to generate feasible solution with acceptable coverage of the hotspots. Future work should build upon this simulation, aiming to im-prove the obtained solution by implementing an iterative improvement algorithm.

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APPENDIX A

The box plot of HPGH and NNGH solution distributions