Location-allocation models for the traffic police routine patrol vehicles on an interurban network

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Abstract

Covering a road network within a pre-specified time frame is the primary objective of any emergency service, including ambulances, firefighters and police. This research investigates the traffic police routine patrol vehicle assignment problem on an interurban road network. The difference between this and other emergency services is the need to consider additional requirements beyond the calls for service. The patrol vehicles must be dynamically located for presence and conspicuousness, in particular at hazardous spots and on roads with heavy traffic volume, in order to prevent traffic offences. Therefore the location choices are of importance in their own right, providing general benefits beyond that of ensuring that the legal requirements for service coverage are fulfilled. In addition, allocation is of importance and may not follow the shortest path condition, rather a cost-benefit analysis, for example, excessive congestion. We develop integer linear programs and apply them to a case study of the northern part of the interurban road network of Israel, using a geographic information system to map the illustration. Finally, the results of the models are compared and contrasted to the locations currently chosen.

Keywords: Network, Location-allocation, ILP, Emergency service

1. Introduction

The ability to cover a network within a pre-specified time frame is one of the most important objectives of the emergency services, including ambulance, firefighting and police services. The emergency service must provide reasonable service levels in order to ensure public safety and security. These services are typically provided by vehicles based at fixed or dynamic locations. The number and placement of vehicles generally influences the quality of services offered. Increasing the number of vehicles is often limited by capital constraints. Under severe constraints, the efficient deployment of emergency service vehicles becomes a crucial issue [1].

The traffic police routine patrol vehicles (RPVs) assignment problem is different to that of other emergency services because of the multi-criteria nature of the issues involved. The traffic police fulfill two major functions: enforcing traffic laws and assisting road users. Through advanced planning, each vehicle is located to "an enforcement-stretch" (node on the network) where it is stationed and enforces the law by issuing traffic reports as well as showing a presence. Each patrol vehicle is also allocated an extended area as part of its territory of responsibility. After a call for service is received, the control room dispatches an appropriate vehicle and the total time span includes the time taken to drive to the call from the enforcement-stretch, the time spent dealing with the problem and the time required to return to the original location. A legal requirement specifies the maximum time permitted to arrive at a call for service's location.

In this research, location-allocation models for the traffic police vehicle on a rural network are formulated. The objectives considered in the models include maximum benefits from RPVs' presence and conspicuousness measured from the traffic volume passing the RPVs. The model determines the optimal base locations for a limited number of vehicles. The service level objectives are optimized through complete network coverage drawn from the traffic police vehicles location and allocation based on legal and additional definitions. We develop integer linear programs and apply them to a case study of the northern part of the interurban roads of Israel.

The research is further organized as follows. Section 2 is devoted to a literature review. Section 3 describes the case study and the current locations chosen by the existing police traffic model. Section 4 presents the standard covering model solutions and includes the main proposed formulations appropriate to the routine patrol vehicle function. Finally, conclusions are presented. In all relevant sections, computational results of the proposed models with respect to the case study demonstrate the effectiveness of the solution's approach and all results are presented using a geographical information system (GIS).

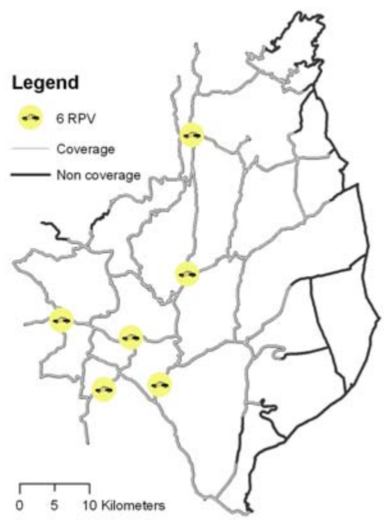
2. Literature review

Location-allocation analysis refers to the modeling, formulation and solution of a class of problems that can best be described as siting facilities in some given space. The assumption is that the optimal location-allocation solution will achieve an efficient level of service [5]. Resource allocation to geographical areas is important in both the private and public sectors. Typically, defining objectives in public sector models is much more complicated than those of the private sector. Frequently, the private sector maximizes profits or minimizes costs, whereas the public sector objectives are often less tangible [11]. In the location-allocation literature, there is a special focus on the rescue services including ambulances, fire stations and police stations [3,4]. In some instances, particularly when emergency facilities are to be located, decision makers may wish to ''cover'' customers. A customer or demand node is said to be covered by a facility, if the distance or time between a client and its closest facility is no greater than a pre-specified value, *S*, representing the distance or time standard. While the problem is formally NP-hard, large instances of network-based location set covering problems have been solved relatively easily using integer linear programming [11]. In the literature, a number of location models have been developed [10]. The coverage formulations deal mainly with two types of problems: the set-covering model (SCM) evaluates the minimum number of vehicles needed to cover all demand within a pre-specified time [12] and the maximum covering location model (MCLP) locates a fixed number of facilities such that the number of demand nodes that can be covered in a pre-specified time limit are maximized [2].

3. Case Study: Northern Israel Interurban Road Network

Our models will be demonstrated using a case study based on the interurban road network of Northern Israel. The real road network is sparse consisting of 49 intersections and 73 arcs. The case study includes approximately 600 km of roads reduced to 222 nodes of digitization on the map, thus each node represents an average 2.5 km of road between nodes. The current police protocol calls for a maximum arrival time of 20 minutes after a call for service has been received. This is translated into 27 km (driving at the speed of 80 km/h on average) for the cover constraint. The ALLOCATE command in the GIS software [7] has been used to assign portions of a network to the current locations based on the 27 km predetermined criteria. All 6 RPVs currently employed are located on major arteries covering the majority of the traffic volume, car accidents and other events (Figure 1).

Figure 1: Current police patrol vehicle location-allocation solution



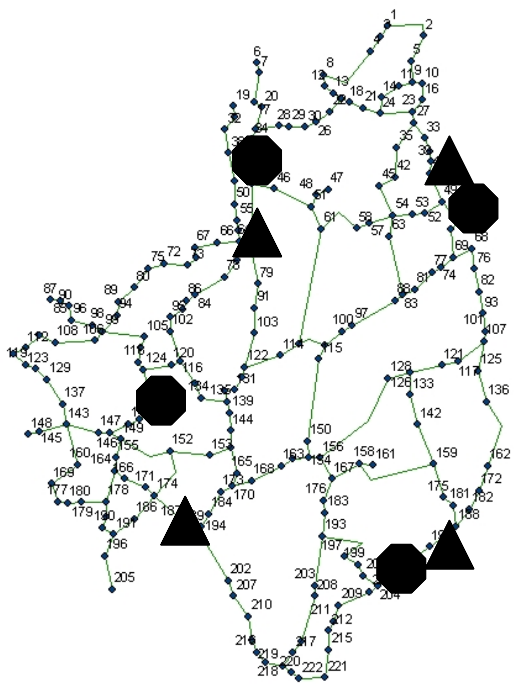
The objective function value was 5,648 i.e. an average of 5,648 vehicles will drive past six routine patrol vehicles in an 8-hour shift, given the locations chosen without the “lost” time during which the RPVs leave their location to handle traffic events within their allocation. This is 85% of the maximum traffic volume value that can be achieve with 6 RPVs on this road network, regarding only the traffic volume data and without call for service data. The pale sections (figure 1) represent roads covered according to the police protocol, whereas the bold sections are currently not covered. The coverage percentage today is 80%. However, as a result, the eastern part of the network is not covered within the pre-specified legal time limit.

4. The Routine Patrol Vehicle Location-Allocation Models

We first present the set-covering problem (SCP) and the maximum covering location problem (MCLP) solutions, using CPLEX 7.0. A pre-processing stage was first undertaken to compute N_i, the set of nodes within acceptable distance of node *i,* for all

222 nodes, by using the shortest-path Dijkstra algorithm. The SCP and MCLP solutions determined that 4 RPVs are sufficient to fully cover the area, less then the existing 6 RPVs (Figure 2 - SCP in triangle, MCLP in octagon). Therefore it should be noted that there are multiple solutions fully covering the network with 4 RPVs. Using dynamic formulations for ILP problems [13], we found 19 different solutions.

Figure 2: SCP and MCLP solutions (4 RPVs)



The SCP and MCLP models do not account for the traffic volume and the calls for services distribution. Given that the police currently possess 6 RPVs, two more than required for complete coverage, we develop models that search for improved solutions by taking into account additional tasks beyond pure coverage.

Formulation 1 is an example of one of our models, entitled the "maximum utility accounting for calls for service model". The formulation is in the form of a cover problem with an objective function that maximizes the benefit from the location less the time required for the RPVs to handle calls for service including the travel time, itself a function of the location. The objective function maximizes police conspicuousness as a function of traffic volume *Uj* [9] in an 8 hours shift. The assumption is that higher traffic volume means that more vehicles will see the RPV thus increasing the halo effect [8]. The objective function minimizes the time the RPVs are not at the chosen locations. The data includes the average number of calls for service to node i (C_i) which was collected for the case study network over a 2 month period from April-May 2007. The travel time between nodes, t_{ij}, as computed based on the Dijkstra solution which considers the network structure and the 27 km allocation restriction with additional time included to account for congestion where relevant. Constraint (1a) requires the solution to locate exactly P RPVs and it is assumed that there are sufficient RPVs to cover all sections (as was previously checked). Constraint (1b) requires each node *i* to be covered by exactly one RPV located at node *j* providing the allocation solution. Constraint (1c) requires that node *i* may only be covered by an RPV at location *j*, if and only if an RPV has been located at node *j*.

Formulation 1: "Maximum utility accounting for calls for service model"

Notation

V set of nodes on network

i, j indices representing nodes where $i, j \in V$

P Number of Routine Police Vehicles

E Average event time (hours) $= 0.5hr$

S equal to 8 hour shifts

Data

N_i set of facility site j within acceptable distance of node i

U_j utility per hour of RPV on section j (as a fraction of traffic volume)

t_{ij} travel time between i and j and back (hours)

C_i average number of events per shift on section i

Decision Variables

$$x_j = \begin{cases} 1 & \text{if RPV is located at candidate section } j \\ 0 & \text{otherwise} \end{cases}$$

$$z_{ij} = \begin{cases} 1 & \text{if section } i \text{ is covered by RPV on section } j \\ 0 & \text{otherwise} \end{cases}$$

$$\max \sum_{j=1}^{V} [S U_j x_j - \sum_{i=1}^{V} (t_{ij} + E) U_j C_i z_{ij}] \qquad (1)$$

subject to

$$\sum_{j=1}^{V} x_j = P \qquad (1a)$$

$$\sum_{j \in N_i} z_{ij} = 1 \qquad \forall i \qquad (1b)$$

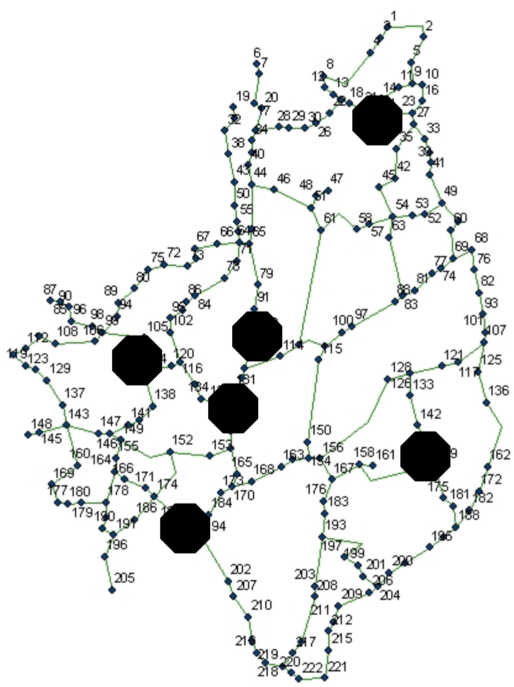
$$z_{ij} \le x_j \qquad \forall j \in (N_i = 1), \forall i \qquad (1c)$$

$$x_j \in \{0,1\} \qquad (1d)$$

$$z_{ij} \in \{0,1\} \qquad (1e)$$

In total 14,532 binary decision variables were defined and the results included 4 locations on main roads and two for purposes of coverage on side roads to the east of the area (Figure 3). The objective function value was 4,320 i.e. an average of 4,320 vehicles will drive past six routine patrol vehicles in an 8-hour shift, given the locations chosen and the average "lost" time during which the RPVs leave their location to handle traffic events within their allocation. This objective function value is 65% of the maximum possible because is considers the coverage and the calls for service constraints.

Figure 3: Maximizing conspicuousness with calls for service



5. Conclusions

This research focuses on the routine patrol vehicle (RPV) traffic police problem on a rural road network. The current traffic police model locates six vehicles such that 80% of the northern Israel road network is covered, i.e. an event is served by a police vehicle within 20 minutes of the call being received. Utilizing two standard models, the set covering problem and the maximum covering location model, we discovered that four vehicles would in fact be sufficient to cover the entire network. Hence questions arose as to whether it was possible to utilize all police resources with complete coverage and provide additional benefits.

To this effect, we develop an integer linear program that locates six routine patrol vehicles such that the entire network is covered according to the legal standards. The formulation maximizes utility defined in terms of presence and conspicuousness, utilizing traffic flow data and considers the time spent dealing with calls for service. It is immediately apparent that the solutions accounting for the calls for service were more widely spread over the network.

Bibliography

[1] C. Araz, H. Selim and I. Ozkaraham, *A fuzzy multi-objective covering-based vehicle location model for emergency services*, Computers & Operations Research 34 (2007) pp. 705-726.

[2] R. Church and C. Revelle, *The maximal covering location problem*, Paper of the Regional Science Association 32 (1974) pp. 101-118.

[3] R. Church, P. Sorensen and W. Corrigan, *Manpower Deployment in Emergency Services*, Fire Technology 37 (2001) pp. 219-234

[4] M.S. Daskin, *Application of an Expected Covering Model to Emergency Medical Service System Design*, Decision Sciences 13(3) (1982) pp. 416-439.

[5] M.S. Daskin, *Network and Discrete Location – Models, Algorithms and Applications*, John Wiley & Sons, Inc 1995.

[6] E.W. Dijkstra, *A note on two problems in connection with graphs*, Numerische Mathematik 1 (1959) pp. 269–271.

[7] GIS by ESRI, ARC/info Ver 7. Network Analysis 1994.

[8] A.S. Hakkert, A. Yelinek and E. Efrat, *Police surveillance methods and police resource allocation models*, The International Road Safety Symposium, Denmark, September 1990.

[9] Israel Central Bureau of Statistics, Traffic volumes, 2006

[10] S.H. Owen and M.S. Daskin, *Strategic facility location: A review*, European Journal of Operational Research 111 (1998) pp. 423-447.

[11] C.S. ReVelle and H.A. Eiselt, *Location analysis: A synthesis and survey*, European Journal of Operational Research 165 (2005) pp. 1–19.

[12] C. Toregas, R. Swain, C. ReVelle and L. Bergman, *The location of emergency service facilities*, Operations Research 19 (1971) pp. 1363-1373.

[13] J.F. Tsai, M.H. Lin and Y.C. Hu, *Finding multiple solutions to general integer linear programs*, European Journal of Operational Research 184 (2008) pp. 802–809.