THE POLICE VEHICLE LOCATION-ALLOCATION PROBLEM

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ABSTRACT

The main aim of this research is to develop and apply location optimization formulations in conjunction with a geographic information system (GIS) to allocate police patrol vehicles such that the police car road coverage in a specific area is maximized. We will demonstrate this using a case study based on the interurban road network of Northern Israel.

Currently it is standard practice around the world to allocate routine police vehicles based on an analysis of the frequent accidents on the roads, commonly known as 'hazardous locations'. In Israel, a traffic model assigns vehicles based on accident severity and traffic volume. The assumption to date is that the presence of a police vehicle on roads with high traffic volumes, which generally also have large numbers of accidents, will reduce both the number of traffic violations and the number and severity of accidents. The problem with the current analysis is its failure to account for the response time of the same vehicles that are required to deal with additional events to which they are called, such as accidents, obstacles reported on the road, congestion and other events. This research therefore discusses the application of the maximum covering location problem taking into account simultaneously 'hazardous locations', traffic volume and maximum coverage of the relevant sectors. The results of the model will enable improved coverage of the network that maximizes the traffic volume capture hence reducing response time to relevant events and improving police efficiency.

Keywords: Police vehicle location, Police vehicle allocation

1. INTRODUCTION

Emergency services such as ambulance systems, fire departments and police vehicles must provide reasonable service levels in order to ensure public safety. These services are typically provided by vehicles based at fixed 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, therefore the efficient deployment of emergency service vehicles is a crucial issue (Araz et. al., 2007). The emergency service vehicle location problem (Toregas et al., 1971) determines the best base locations for vehicles such that specific service level objectives are optimized. Coverage of the network is one of the most important objectives, reflecting the quality of emergency services. Therefore, emergency service vehicles must be located in such a way that they may reach any demand point within a maximal response time (Araz et. al., 2007).

In this research a traffic police vehicle location-allocation model on a rural network is proposed. The model maximizes presence and conspicuousness through complete network coverage given a limited number of routine patrol vehicles (RPV). Different solution approaches, such as integer linear programming and tabu search using a GIS software, are presented using map illustrations of a case study of the Northern part of the interurban network of Israel.

The paper is further organized as follows. Section 2 presents a brief literature review of the existing models related to the emergency service vehicle location. In Section 3, the rural traffic police vehicle problems are described. Section 4 is devoted to the GIS application. In Section 5, the linear programming results are shown and conclusions are presented in the last section.

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. Generally there are four components that characterize location problems: (1) customers to be allocated to facilities, who are presumed to be located at points or on routes, (2) facilities to be located, (3) a space in which customers and facilities are located, and (4) a metric that indicates distances or times between customers and facilities (ReVelle, 2005). The assumption is that the optimum location-allocation will improve efficiency and level of service (Daskin, 1995).

Resource allocation to geographic areas is important in both the private sector and the public sector. Typically, defining objectives in public sector models is much more complicated than those of the private sector. Most often, the private sector maximizes profits or minimizes costs, whereas the public sector objectives are less tangible (ReVelle, 2005).

In the location-allocation literature, there is a special focus on the rescue services including ambulances, fire stations and police stations (Church, 2001; Peleg, 2000; Toregas et. al., 1971). 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 (ReVelle, 2005). In the literature, a number of location models have been developed (see Owen et al., 1998 for a survey). The coverage problem deals mainly with two types of problems: (1) The set-covering model (SCM), originally proposed by Toregas, Swain, ReVelle and Bergman (1971), evaluates the minimum number of vehicles needed to cover all demand in a pre-specified time limit and (2) The maximum-covering-location model (MCLP), originally formulated by Church and ReVelle (1974), locate a fixed number of facilities that maximize the number of demand nodes that can be covered in a pre-specified time limit. For example, the legal standard may be the ability to respond to 90% of the calls to an Emergency Medical Service (EMS) within 8 minutes (Church, 2001).

Geographic information systems (GIS) have been broadly applied in many public sectors: Peleg (2000) studied the location-allocation of ambulances in Israel, providing a solution with the aid of a GIS whereby the ambulance was manually assigned according to the likelihood of events. The output is an area map showing points to which ambulances are assigned and the area to be covered by each ambulance (according to the response time). In addition, the solution specifies the percentage of events covered and the probability that an ambulance will not be available. Bédard et. al., (2003) present a decision-support tool that combines additional uses of GIS and optimization including GIS and on-line analytical processing technologies to facilitate geographic knowledge discovery in the field of environmental health. The proposed system provides fast and easy access to the detailed and aggregated data that are needed for decision-making in the public health sector. Naesset et. al., (1997) propose a combination of GIS and linear programming to develop a new forest management system.

3. THE CURRENT METHODOLOGY OF THE TRAFFIC POLICE

The traffic police fulfill two major functions: enforcing traffic laws and assisting road users. The main methods used to attain these functions include: 1) maintaining presence and conspicuousness 2) issuing reports of traffic violations 3) handling vehicle accidents and other traffic events 4) directing traffic and 5) accompanying special convoys. The National Traffic Police (NTP) in Israel is in charge of all traffic aspects on interurban roads in Israel. NTP allocates the traffic patrol vehicles to routine work and to special operations. The special operation vehicles are involved in convoy accompaniment and enforce the traffic laws through a concentration of forces in a specific place, time or offence. The routine patrols perform all remaining tasks. In addition, there are automatic enforcement devices to catch speeding and red-light offences. Here we will focus on the routine patrol vehicles (RPVs). Through advanced planning, each vehicle is allocated “an enforcement-stretch” (section of road) 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. When an event occurs, the control room dispatches an appropriate vehicle to deal with the event. If busy, the nearest patrol vehicle available will be dispatched. A protocol specifies the maximum time allowed to arrive at an event.

The enforcement-stretches were initially specified based on engineering and operational parameters. In Israel, patrol vehicles are assigned to enforcement-stretches according to a "traffic model". The assumptions of the model are that the presence and conspicuousness ought to be higher where traffic volume and number of accidents are higher, acting as a deterrent and reducing the likelihood of traffic offences, hence resulting in a reduction in the number of road accidents and their severity. Furthermore, the presence of the police on the roads with statistically the most accidents reduces the time of arrival of the patrol car to these kinds of events. Therefore, the model weights the enforcement-stretches based on historical data including the number of accidents, their severity and the traffic volume. The output of the "traffic model" is a ranked list of enforcement-stretches (Hakkert et. al., 1990).

4. THE GIS APPLICATION

The main aim of this research is to utilize optimal location formulations in conjunction with a geographic information system (GIS) to allocate police patrol vehicles such that the police coverage of roads in a specific area is maximized. We will demonstrate this using a case study based on the interurban road network of Northern Israel. The case study (Fig 1) includes approximately 687 km of roads (382 km are main roads identified by a 2 digit code). The road network is sparse and includes 49 intersections and 73 arcs. The current police protocol calls for a maximum arrival time measured from a call for service (CFS) of 20 minutes. This is translated into 27 km (driving at the speed of 80 km/h on average) for the cover constraint. The ESRI GIS software (ARC GIS 9 Desktop) was applied, to present the current solution discussed in section 4.1 and then to solve a maximum cover location problem (MCLP) using the locate-allocate heuristic (with ARC Info 9 Workstation) discussed in section 4.2. In section 5 we present the optimization model, the results of which will be compared to those of this section.

4.1 Current Traffic Police Location Solution

Utilizing ARC GIS 9, the ALLOCATE command assigns portions of a network to a location based on predetermined criteria. The 6 cars in figure 1 present the current “enforcement-stretches” (section of roads) in which the traffic police are currently located. The patterned sections present the roads covered according to the police protocol, whereas the bold sections are currently uncovered. The coverage percentage today is 80%. As highlighted in figure 1, the 6 RPVs have been located on major arteries covering the majority of the traffic volume, road accidents and other events. However, the eastern part of the network is not covered as a result.

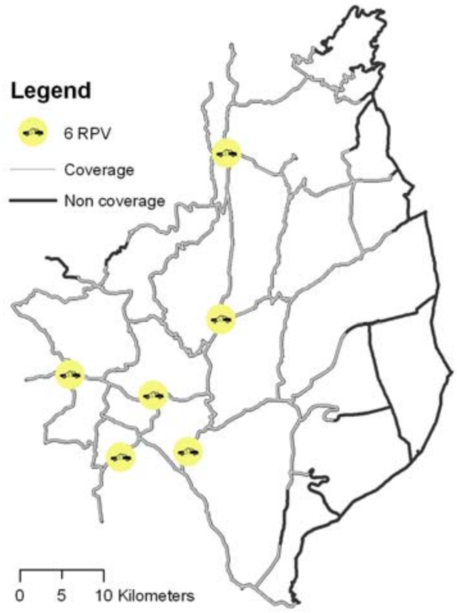


Fig 1: Current police patrol vehicle location-allocation solution

4.2 A Maximum Covering – Location Solution

We applied the LOCATE-ALLOCATE tabu search algorithm (ESRI, 1994) in order to determine the configuration of facilities (locations) and assignments of demand to the respective facilities according to chosen criteria. The criteria applied were based on the maximal covering location problem (MCLP), which maximizes demand covered within a specified time or distance. Fig 2 presents the solution to this problem. The coverage percentage increased to 95%, a substantial improvement over the existing solution without adding any additional resources. The locations in figure 2 place the RPVs on smaller, side roads (i.e. 3 digit roads rather then the 2 digit roads chosen under the current solution) as listed in Table 1. Hence, whilst greater coverage is achieved, this solution reduces the visibility with respect to traffic volume.

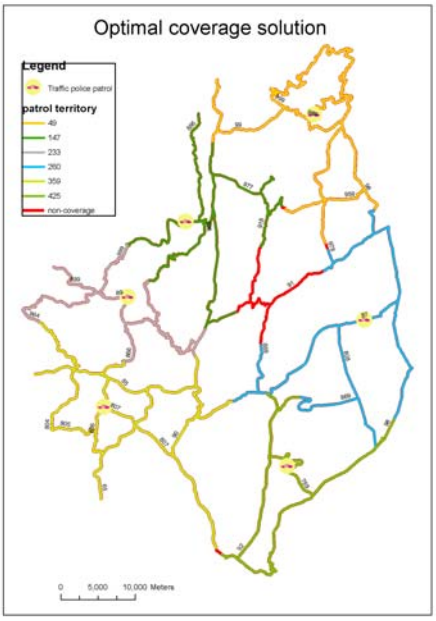


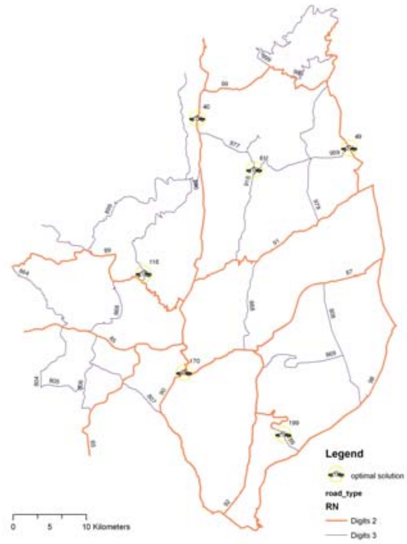
Fig 2: The MCLP heuristic solution

5. LINEAR PROGRAMMING RESULTS

The integer programs were run on CPLEX 7.0 (with a Matlab 7.0 interface), analyzing the Northern part of the interurban network of Israel. The GIS digitations divided the network into 222 nodes with average distances between nodes of 2.5 km. After pre-processing using the Dijkstra algorhithm to compute the O-D matrix, 14,310 potential allocation variables, *Zij*, were defined:

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

Together with the 222 options for locations, *Xj (*The binary decision variables), 14,532 decision variables were defined, in total. The solution was that 6 RPVs are sufficient to ensure 100% coverage of the network. The location sites include 4 two-digit main roads and 2 three-digit smaller roads (Fig 3).



6. CONCLUSIONS AND FURTHER DIRECTIONS

In this research we focused on a location-allocation problem of the RPV (Routine Patrol Vehicle) of the traffic police vehicles on a rural road network. We have compared MCLP heuristics within the GIS software versus an optimal solution based on our model. On our case study network, the heuristic had poor results (less coverage, fewer main roads) compared with the IP solution (Table 1).

Table 1: Summary of the 6 RPVs locations and the results

	Location on the roads (red: main roads - 2 digits)	% coverage	# main roads
Today	90,90,90,85,85,65	80%	6
MCLP - heuristic (GIS)	89,87,989,899,807,789	95%	2
MCLP - optimal (Cplex)	90, 90, 98, 89, 977, 789	100%	4

In further research we plan to add more parameters including time to handle events and evaluating dynamic locations for better deterrence.

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