Chapter XIII

Integrating GIS and Maximal Covering Models to Determine Optimal Police Patrol Areas

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Abstract

This chapter presents a new method for determining the most efficient spatial distribution of police patrols in a metropolitan region, termed the police patrol area covering (PPAC) model. This method employs inputs from geographic information systems (GIS) data layers, analyzes that data through an optimal covering model formulation, and provides alternative *optimal solutions for presentation to decision makers. The goal of this research is to increase the level of police service by finding more efficient spatial allocations of the available law enforcement resources. Extensions to the model that incorporate variations in the priority of calls for service based on the type of crime being committed, and the need for an equitable distribution of workload among police officers are discussed. Examples of the inputs from – and outputs to – GIS are provided through a pilot study of the city of Dallas, Texas.*

Introduction

Virtually all metropolitan police departments in the U.S. create a geographic division of their area for the purposes of administration and patrol. The way in which this spatial division is made influences the provision of police services. An optimal spatial division could equitably distribute limited police resources throughout the city, reduce response times, save money through efficient deployments, and create a fair division of risk among police officers.

The primary goal of this research is to provide suggestions that will lead to an increase in the level of police service by finding more efficient spatial allocations of law enforcement resources. We take care to note here that efficiency can be a broadly defined term – with multiple metrics – and we restrict ourselves to the spatial efficiency of the patrol-area boundaries. The resulting alternatives take the form of optimal solutions to maximal covering problems, which delineate police patrol areas. These problems must be solved in the context of a major metropolitan area, with a large population and a concomitantly large number of potential police patrol areas. It is proposed that covering models hold the greatest promise for determining optimal solutions to the problem of delineating police patrol areas. Given the difficulties inherent in optimally solving large instances of such problems, both GIS and integer programming software must be integrated in order to allow these problems to be re-examined when the initial conditions change. Given the many people and organizations who must approve the changes suggested by the optimal solutions that are found, the results must be presented as a series of alternatives from which a best arrangement can be selected that satisfies the greatest number of people and that can be efficiently implemented.

The relevant literature that forms the basis for this research falls into three major categories: the discipline of location science and its integration with GIS, the determination of police patrol areas and the formulation of covering models for service provision to geographic areas. In addition to these three categories, there are pertinent bodies of literature surrounding the methods for solving problems optimally, which will be discussed in more detail in the methodology section below.

Location Science and Optimization

The field of operations research (OR) – also termed management science – is defined as the generation and application of advanced analytical techniques in order to solve complex problems and make organizational decisions (Curtin, 2004). Often these problems involve the allocation of scarce resources in such a way as to maximally achieve a goal (such as profit or level of service) or minimize a negative consequence of the operation of an organization (such as cost or environmental degradation). Although this discipline has its origins in the application of problem-solving techniques in a military context, a wide range of industrial, transportation, social and ecological applications have been developed over the past several decades (Hillier & Lieberman, 1995).

A substantial subdiscipline within OR is the field of location science, where the geographic location of facilities or activities within the system or organization is a primary determinant of the optimal solution (Hale, 2004). Within location science, a sub-set of problems and methods are concerned with both the location of facilities *and* the allocation of demand to those facilities, and research in this area is termed location-allocation theory. Unfortunately, large instances of many problems in location science are practically impossible to solve optimally. While it is conceivable that every possible competing solution could be compared through an evaluation of the objective function (known as enumeration of all possible solutions), this method quickly becomes impractical. The number of alternatives is a function of the number of facilities to be located and the number of potential facility locations. In general the number of alternatives will be:

$$\left(\frac{n}{p}\right) = \frac{n!}{p!(n-p)!}$$

where n = the number of potential facility locations, and p = the number of facilities that one wants to locate among those potential sites. The number of alternatives can thus grow rapidly as the values of n and p increase. So rapidly, in fact, that as the size of a problem of this type increases, it becomes impossible to enumerate all answers in a reasonable amount of time. If a decision problem is intrinsically harder to solve than those that can be solved by a non-deterministic

Turing machine in polynomial time is classified as NP-Hard (NIST, 2001). Optimization versions of these decision problems are termed NP-Complete.

In order to solve the complex problems posed within location science, these problems must be formulated in such a way that they can be efficiently analyzed, and this generally requires the formulation of a mathematical model. These models commonly take the form of an objective function, which defines the goal of the organization (or one of many goals), and a set of constraints representing the conditions within which the system must operate. Once the general version of problem is formulated, individual instances of that problem can be solved optimally in order to suggest specific distributions of the organization's resources. The optimal solution will be the one that best satisfies the objective that had been optimized. In the context of the research presented here, one potential objective is to provide the highest level of service by delineating the optimal arrangement of police patrol areas. The success of that solution can be measured by the number of incidents to which the police can respond within an acceptable service time. We caution that this approach does not suggest that all administrative issues be simplified through a broad acceptance of response-time reduction. Instead, this approach, like others, should be used to determine appropriate alternative deployments for particular types of calls, and used in the context of overall agency objectives. The constraints on this system include the number of police patrols that are available, the level of workload that can be assigned to each patrol, and numerous other economic and legal restrictions on police activity.

The application areas to which location science has been applied are far too numerous to list here, but it is clear that the efficiencies that can be gained by mathematically modeling a system and solving that model optimally are significant and can in some cases be extraordinary. Recent findings show that major corporations have realized savings in the hundreds of millions of dollars attributable to the implementation of optimization techniques (INFORMS, 1999). In the context of the research presented here it is reasonable to expect that these methods could result in savings in terms of money spent on officer salaries, decreased response times and increased revenues from citations based on the more efficient deployment of officers.

Location Science and GIS for Law Enforcement

Although operations research has proven its worth in applications to a wide range of problems, the issue at hand is whether or not it can benefit an application in the field of law enforcement, and particularly in the determination of police patrol areas. The division of an area by a police force is fundamentally a geographic problem. Commonly, a city or metropolitan area is divided into police command areas, variously termed precincts, districts or divisions. These command areas are further divided into patrol areas, sometimes called beats or sectors (Larson, 1978). Several sources confirm that prior to 1972 police patrol areas were determined “by hand,” where a person was responsible for drawing police patrol areas on a map based on their knowledge of the total area to be patrolled by the police force and the available police resources (Mitchell, 1972; Taylor & Huxley, 1989). No other description of formal analysis entered into the procedure for determining police patrol areas, nor was there a quantitative method for evaluating how the hand drawn boundaries compared to an optimal arrangement or for comparing alternative deployment schemes. As late as 1986, a study of departments found that no integer optimization models were in use. This pervasive and persistent lack of formal procedures for police patrol area development has been seen to complicate higher-level policy decision making due to the lack of objective quantitative measures of efficiency (Taylor & Huxley, 1989).

The first application of mathematical modeling to the determination of police patrols known to the authors was a formulation and application for Anaheim, California (Mitchell 1972). This application used a version of the p-Median problem to minimize the demand weighted distance between sectors of the city. The demand weights were a function of the expected number of incident calls in each sector. Several distance metrics were presented and suggestions were made for the differentiation of incidents based on type, for multiple unit response to incidents, and for constraints on work load and maximum response distance. In that application no proven optimal solutions were found, but heuristic solutions based on the Maranzana heuristic (Maranzana, 1964) for dividing a geographic region were determined. Even so, the application of heuristic methods to solve this mathematical model resulted in a 13% to 24% reduction in average response distance when compared to the hand drawn district boundaries.

At about the same time a series of publications of research supported by the Rand Corporation presented the development of a hypercube queuing model for the deployment of police assigned to different police patrol areas (Larson, 1975). A mathematical model of the hypercube could be used to find the optimal deployment pattern *for a pre-determined set of police patrol areas*. An approximation algorithm was also developed to solve these problems more quickly, albeit without a guarantee of optimality. Once a beat plan has been established (by hand) the hypercube queuing model is used to distribute police resources to calls in an efficient manner. Several performance measures of the efficiency of the patrol area plan can be generated (Chaiken & Dormont, 1978b). These measures can be used to compare different beat plans. However, the hypercube queuing model does not determine the optimal arrangement of police patrol areas, rather it allocates police resources within an existing arrangement.

Therefore the performance of a particular patrol area arrangement cannot be compared to the optimal spatial arrangement.

Variations of the hypercube queuing model have been applied in St. Louis County, Missouri (Kwak & Leavitt, 1984), and New Britain, Connecticut (Sacks, 2000). In these applications, it is suggested that the police department ought to try redrawing different arrangements of districts in order to compare the solution values with the performance measures generated by the hypercube queuing model. Given the combinatorial complexity of the districting problem it is highly unlikely that the optimal solution will be determined in this way, and there is no way of knowing if the optimal solution to the problem of drawing district boundaries has been reached through trial and error.

Where operations research techniques have been employed in law enforcement contexts it has been noted that the results of these analyses are sometimes the only quantitative information provided to decision makers (Aly, Litwhiler & Heggy, 1982). However, virtually all of the applications of operations research has focused on scheduling (Chaiken & Dormont, 1978a; Taylor & Huxley, 1989), and it appears that additional models are necessary to determine the optimal arrangement of police patrol areas which can then be used to allocate police resources with an efficient schedule. This research employs a set of models of the type known as covering models to address the current deficiency in the literature and in practice.

In contrast to operations research techniques, geographic information systems have become widely accepted among police departments as a valuable tool for a wide range of applications. Perhaps most importantly, GIS has been used to assist in the determination of clusters of crime activity, termed hot-spots (Craglia, Haining & Wiles, 2000; Harries, 1999). However, even well-informed and experienced GIS users labor under the misconception that state-of-the-industry GIS packages can optimally solve combinatorial optimization problems with the push of the button. While they are extraordinarily useful tools, a close examination of the supporting documentation for GIS software packages demonstrates that they are NOT designed to solve such problems optimally (ESRI, 2004). In fact, only a very limited number of problems can be solved, and even this limited set of problems can only be solved heuristically, generally using versions of interchange heuristics such as the Tietz and Bart (Teitz & Bart, 1968) or GRIA (Zanakis, Evans & Vazacopoulos, 1989) heuristics. The difficulties in solving combinatorially complex location science problems within GIS have been well documented (Church, 2002), and the heuristic solution procedures have been described as providing "a minefield of local optima" (Church & Sorenson, 1994), which can lead to substantially suboptimal solutions. Even if the heuristic solution procedures embedded in out-of-the-box GIS packages provide a good solution, there is no way of knowing whether of not the optimal solution has been determined, or how close the solution is to optimal. Although there are superior heuristic procedures such as those that employ simulated annealing (D'Amico, Wang, Batta & Rump, 2002), these heuristics require sophisticated users to test and apply parameters. For this reason they are not built into off-the-shelf GIS software packages. Due to this limitation, this research demonstrates that GIS can be integrated with integer programming solution software to find optimal solutions to the problem of delimiting police patrol areas. This research presents an optimal covering model as a reasonable and flexible choice for designing police patrol areas when integrated with GIS.

Covering Models

The maximal covering location problem (MCLP) was first formulated in 1974 (Church & ReVelle, 1974). The MCLP seeks to find the solution to the problem of locating facilities (such as police cars on their beats) in such a way as to maximize the number of incidents that can be served within a given service distance (or response time). Because the MCLP has been shown to be NP-Complete, robust solution procedures must be developed to allow the optimal solution to be found. A number of solution procedures and reformulations of the problem to facilitate solution have appeared in the literature. Additionally, the MCLP has been related theoretically to other prominent location models including the p-Median model and the location set covering model (Church & ReVelle, 1976). These links between models allow solution procedures developed for one of the problems to be applied to the others. Heuristic solution procedures such as the TABU search heuristic (AdensoDiaz & Rodriguez, 1997) and Langrangean relaxation heuristics (Galvao, Espejo & Boffey, 2000; Galvao & ReVelle, 1996) have also been developed for the MCLP.

Additional areas of research that can provide insights into potential problems when applying covering models to the determination of police patrol areas include an analysis of data aggregation errors (Current & Schilling, 1990) and the inclusion of capacities on workloads (Pirkul & Schilling, 1991). A variant of the MCLP has been developed to ensure that not only is coverage maximized but that travel times or distances to service demand outside the maximal covering distance is minimized (Church, Current & Storbeck, 1991). The formulation of the maximal conditional covering problem suggests that "backup" coverage can also be modeled for police patrol areas (ReVelle, Schweitzer & Snyder, 1996).

Covering models have been applied to the location of emergency warning sirens (Current & Okelly, 1992), the location of ambulance bases in a rural region (AdensoDiaz & Rodriguez, 1997), integrated fire and ambulance siting (ReVelle & Snyder, 1995), the location of retail facilities (Berman & Krass, 2002), and ecological reserve selection (Church, Stoms & Davis, 1996). A review of applications of the MCLP that do not involve geographic location (Chung, 1986) found that the model was proven useful for data abstraction and statistical classification. To date no application of the MCLP to the determination of patrol areas has appeared in the literature.

Police Patrol Area Covering (PPAC) Model

Maximal covering models can be applied to the problem of generating optimal police patrol areas with the following formulation:

$$\text{Maximize } Z = \sum_{i \in I} a_i y_i$$

Subject To:

$$\sum_{j \in N_i} x_j \geq y_i \quad \text{for all } i \in I \qquad (1)$$

$$\sum_{j \in J} x_j = P \qquad (2)$$

$$x_j = (0,1) \quad \text{for all } j \in J \qquad (3)$$

$$y_i = (0,1) \quad \text{for all } i \in I \qquad (4)$$

Where:

I = the set of known incident locations;

J = the set of potential locations for police patrols;

S = the acceptable service distance (surrogate for desired response time);

d_{ij} = the shortest distance from incident location i to police patrol location j;

x_j = 1 if a police patrol is located at potential site j, and 0 otherwise;

y_i = 1 if an aggregated crime location at i is covered by at least one l located police patrol area, and 0 otherwise;

N_i = $\{j \text{ in } J \mid d_{ij} \leq S\}$;

a_i = weight of crime incidents at incident location i;

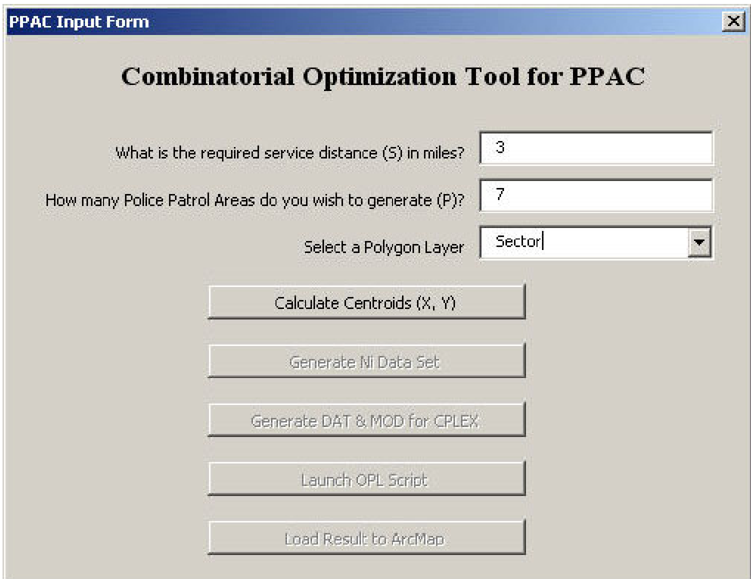
P = the number of police patrol areas to be located.

In this formulation N_i is the set of facility sites eligible to provide "cover" to incident location i. In the context of patrol area development, N_i is the set of crime incident locations that can be served within the acceptable response time, S. S can vary for different types of incidents, which may require faster response times. Keep in mind that although d_{ij} and S do not appear directly in the formulation, they are included in constraints (1) through the inclusion of the sets N_i. The objective is to maximize the number of incidents served or "covered" within the acceptable response time. Any subset of crime incidents may be used to populate the set I. As an example, if there are seasonal trends in crime incidents, it may be appropriate when defining patrol areas for a given week (or month) to consider just those incidents that occurred during the same week (or month) of the previous year. Constraints of type (1) allow y_i to equal 1 only when one or more patrol cars are established at sites in the set N_i. The number of patrol areas to designate (P) is limited to the number of available patrol cars by constraint (2). Constraints (3) and (4) require that only integer values are included in the solution. That is, police patrols cannot be split between patrol areas.

The PPAC model assumes a priori that an acceptable level of service (measured as a response *distance*) has been agreed upon as representing an acceptable level of citizen safety. This assumption is reasonable based on recent findings that police response time can be a significant determinant in the evaluation of police performance (Priest & Carter, 1999). While research has shown that response times have little bearing on the volume of crime in a jurisdiction (Sherman, Gottfredson, MacKenzie, Eck, Reuter & Bushway, 2004), we caution the reader to regard an important point. While crime reduction is clearly of paramount importance to policing, their efforts to reach this goal do not occur in a vacuum. As are all government agencies, police departments are subject to a number of resource constraints and political realities that make the efficient delivery of services important. Even with little or no reduction in crime rates, an increase in operational efficiency may lead, in turn, to improved effectiveness. Given the limit on police resources, the implementation of PPAC also requires that the number of police patrols is known in advance. This is, in fact, one of the models' strengths given that the amount of financial resources to be allocated to police protection may change quickly and often.

There are three primary objectives in police deployment: citizen safety, cost of operations, and workload balance (Taylor & Huxley, 1989). Consider that citizen safety is generally accepted to be greater when the number of police on duty is increased and therefore response times are decreased, and consider also that the cost of operations are directly related to the number of officers on duty. These objectives are clearly opposed to one another, and therefore solutions must be determined that reconcile these goals based on an acceptable level of service

Figure 1. GIS data collection tool



provision. The PPAC objective of maximal coverage is one attempt to resolve this internal competition.

Solving PPAC by Integrating GIS and Optimization

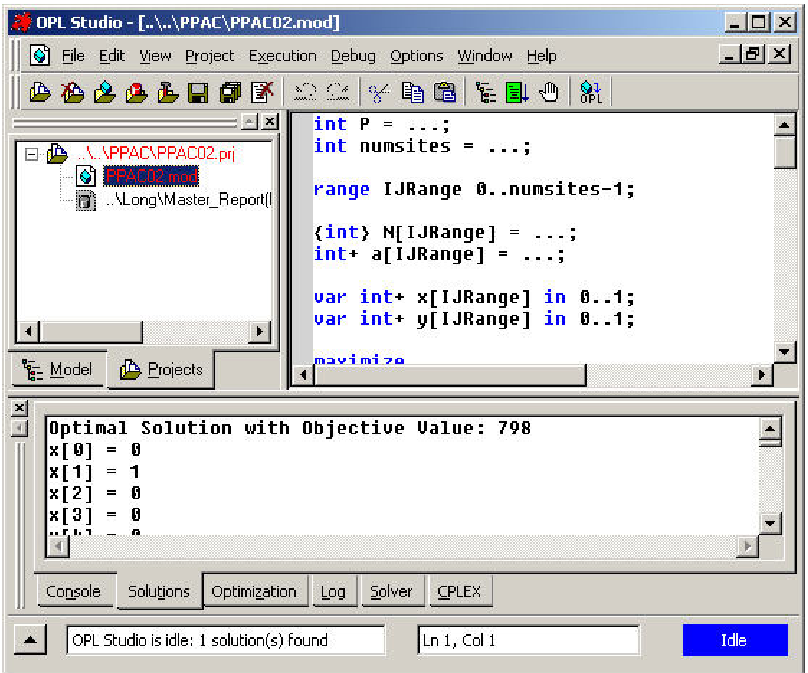
While GIS alone cannot provide optimal solutions to combinatorially complex location problems, it does provide the ideal platform for the assembly of geographic data layers, the collection of model instance parameters from users, and the output of cartographic representations of optimal solutions to decision makers. By integrating GIS with software designed to determine optimal solutions for complex systems, alternatives can be generated in order to inform police policy and practice.

Consider how such integration takes place in the context of solving the PPAC model. For this example and the pilot study in the following section, the ArcGIS Software (specifically, the ArcMap module) and the ILOG Optimization Programming Language (OPL) Studio and CPLEX optimization software for integer programming applications was employed. In order to begin the process of solving PPAC, several model parameters must be collected from the user. ArcMap provides a Visual Basic for Application (VBA) platform where interactive menus can be built to query the user for this data. In the case of PPAC the user must input values for the acceptable service distance (S), the # of patrol areas to generate (P), and the polygon layer from which the optimal spatial arrangement will be built (Figure 1). If the centroids of the polygons are to be used as potential patrol area centers, these can be generated within ArcMap as well. Once the service distance is provide, the sets N_i denoting the possible coverage relationships can be generated within the GIS. This involves the calculation of distances between potential patrol area locations and crime incidents and a pairwise comparison of locations to determine possible coverage. If the crime incident data is associated with the polygons, the a_i values can be computed with standard point-in-polygon GIS query tools. If addresses are available for the crime incidents they can be address-geocoded with the assistance of appropriate GIS tools. All of these functions are well within the capabilities of industry standard GIS software packages. At this point in the process, however, the GIS must surrender this information to the optimization software in order for optimal solutions to be determined. The VBA programming platform can be used to export the model parameter information to a data file that can be read by OPL Studio.

Optimal solutions can be obtained for many location problems by combining the use of a version of the simplex solution method (Dantzig, 1957) on linear programming relaxations of the problem, with a complementary branch and bound technique for dividing the original problem into more solvable sub-problems (Hillier & Lieberman, 1995). The ILOG CPLEX software package employs these methods in combination with procedures for advanced pre-processing of the problems to be solved. Techniques are embedded within the software to reformulate problems to encourage integer solutions and reduce the amount of time and the level of computer resources that are needed to determine optimal solutions. The OPL Studio software allows the general version of the PPAC model to be formulated (Figure 2). It can be launched with commands given from within the GIS. The output parameter file for the particular problem instance can be read and the resulting problem instance submitted to CPLEX for solution with no further input from the user. When an optimal solution is found, the locational decisions (the values of the decision variables) can be exported back to the GIS for display.

Of utmost importance when implementing these models is that they must be accessible to police and associated staff as the primary users. In the past it has been suggested that the mathematical formulations common to operations research are beyond the understanding of all but a few experts in the field (Aly et al., 1982). In order to ensure that this is not the case, the models must be

Figure 2. Optimization software for the processing of GIS-generated model parameters



presented in a clear, and easy to understand format, with cartographic output that can be generated for those who must make the final decision on which solution to implement. In the case of the PPAC model the solution is a set of decision variable values that represent the locations of patrol area centers. The GIS provides the tools for selecting the areas that can be serviced by the chosen patrol area locations, and for dissolving the polygon layer to generate an intuitive cartographic representation of the alternative spatial arrangement. If the boundaries of the patrol areas must conform to other land features (such as census area polygons or traffic analysis zones) then GIS contains functions for the overlay of such layers and the selection of polygons for each police patrol area.

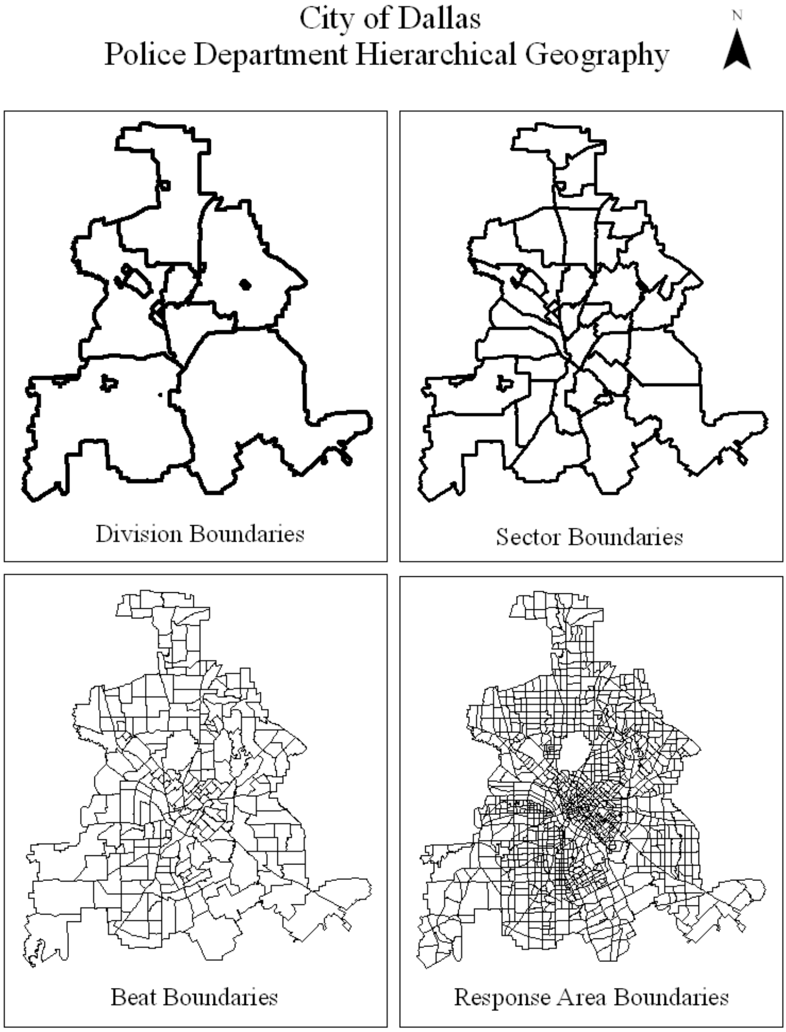
Pilot Study for the City of Dallas, Texas

A pilot study of the applicability of the PPAC Model has been conducted as a proof-of-concept using the geographic boundaries employed by the city of Dallas, Texas, Police Department, and a subset of the incidents to which that department has been required to respond. In the case of Dallas, Texas, there are 7 divisions, 33 sectors, 233 patrol areas (beats) and 1,176 response areas (Dallas Police Department, 2002a) as shown in Figure 3. A sample of 798 calls for service from January 1, 2002, through January 7, 2002, where Dallas Police Department officers responded to 911 hang-up phone calls are used for this test of the PPAC model (Dallas Police Department, 2002b). For any level of the police geographic hierarchy, a spatial division can be created based on any of the lower levels in the hierarchy. That is, beats can be built from response areas, sectors can be built from either response areas or beats, and divisions can be built from any of the three other geographic layers. Each of these permutations was solved optimally in order to generate alternative spatial divisions for Dallas, but for purposes of graphical clarity, and given the time constraints in this format, we present only the instance where divisions are built from the sector level geography.

For the purpose of determining the optimal arrangement of divisions based on sectors, the incident locations were aggregated to the centroid of the sector within which they occurred. This approach exposes the results to aggregation errors, and it would be preferable to have address-geocoded locations of the incidents. Unfortunately such locational specificity was unavailable for this pilot study. The values of i and j can therefore vary from 1 to 33 (the number of sectors). In the case of i, the sector centroids represent the aggregated incident locations. In the case of j, they represent the potential locations for the police patrol areas. Since police patrols are presumed to be traversing their area of patrol responsibility until assigned to a call (Bodily, 1978) there is no way to know in advance the precise location of the police patrol, and therefore the sector centroids represent as reasonable an assumptive location as any others. The value of a_i becomes the sum of the 911 hang-up incidents that occurred in each sector. For this problem instance, one division (and its associated single sector) and another sector were removed from the dataset. These areas represent suburban lakes where no incidents occurred. Therefore, an optimal spatial arrangement of six divisions should be created from a set of 31 sectors used as building blocks. In the PPAC model P is equal to six.

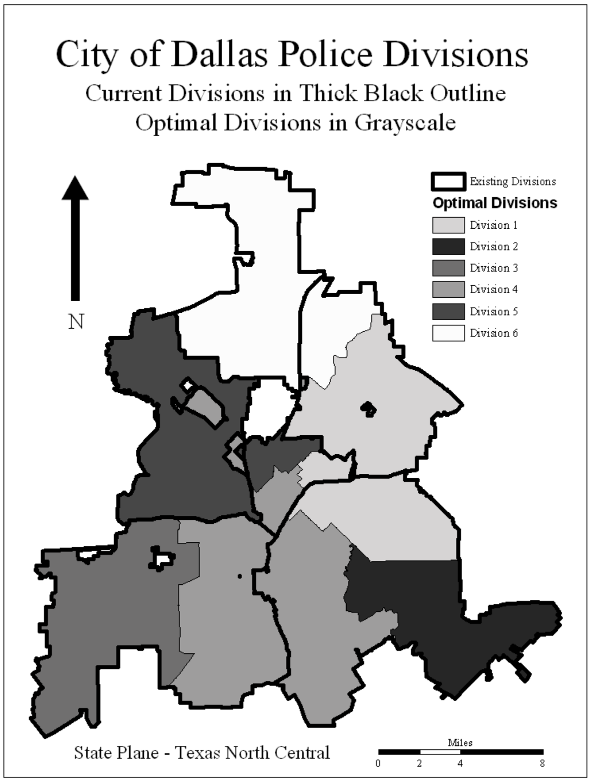
This problem was solved with increasing service distances (S) in increments of one-tenth of a mile until a spatial arrangement was found that covered all of the incidents. The smallest service distance that covers all incidents is 5.1 miles. This service distance was measured using the Euclidean distance between the sector centroids representing the patrol area locations and the aggregated incident locations. Clearly, network distance would be a preferable metric but, once again, address-geocoded locations were unavailable. Once the optimal solution to the PPAC model was found that could cover all incidents with the smallest possible response distance, the optimal spatial arrangement was compared to the current one (Figure 4). In terms of the total distance traveled from police patrol

Figure 3. City of Dallas police geography



location to incident locations, there was a 3.66% reduction using the PPAC optimal solution. In terms of average distance traveled, there was a 3.54% reduction with the PPAC solution. The worst case distance (meaning the longest single distance from a police patrol location to an incident location that it covers) increased by 0.59% with the PPAC solution. Perhaps the most important comparisons are made with the total and average weighted distances, where the weights are the number of incidents at each location. Both of these distance

Figure 4. Current and optimal police divisions



measures showed and improvement of 4.85% with the PPAC solution when compared to the current spatial arrangement.

Although it is satisfying that the PPAC model generated optimal arrangements that improved on the current spatial arrangement, for this particular problem instance (generating division boundaries from sectors) the results could well be interpreted as a verification of the appropriateness of the current arrangement. It would likely not be appropriate to redesign long-standing division boundaries – and incur the concomitant expense – for only a 4.85% reduction in weighted response distances. This highlights the importance of understanding that the optimal solution to location problems are only alternatives to be presented to decision makers for evaluation, and only perhaps for implementation.

Model Refinement

One of the most significant benefits of finding optimal solutions to this problem is the ability to evaluate the models in terms of the improvement that they provide when compared to the existing arrangement of police patrol areas, or when compared to alternative arrangements. However, the optimal solution is only a reflection of the ability of the model to replicate a real-world system. The process of testing the model involves refinements of the model to more accurately reflect the system that the model attempts to represent. The example we present above is designed simply to show the potential power of this approach. The true power lies is developing solutions steeped within the operational and administrative priorities of the agency.

There are several components of the model that can be immediately refined. First, the model formulated above considers each crime location to be of equal importance. Since the test case in Dallas considered only a single type of call (911 hang-up responses) this assumption is reasonable. However, the delineation of patrol areas must consider all of the types of crime incidents that occur. Therefore the measure of demand (a_i) should be a variable that represents the importance of a timely response (a covering) of that incident. Secondly, the model formulation above does not include any constraint on the number of calls that will be located within any particular police patrol area. In other words, there is no guarantee of equity among the police patrol areas. In order to address this deficiency the model can be refined with the addition of a set of constraints of the following type:

$$\sum_{i \in N_j} a_i x_j \leq M \quad \text{for all } j \in J$$

where:

$N_j = \{i \text{ in } I \mid d_{ij} \leq S\}$;
M = the maximum incident load that each patrol area can serve;

The set N_j is defined as all of the crime incident sites (i) that can be served from a potential patrol area centroid (j). There is one constraint for each potential patrol area centroid (j). If a patrol area is centered at j the value of x_j will be 1. If this is the case the constraints will require that the sum of the crime incident values (a_i) for all of the sites i that are covered by j must be less than or equal to the maximum crime incident load that can be handled by any single patrol area.

It is presumed that there are a large number of other potential constraints, and they will fall into several general categories – physical resource constraints, economic constraints, scheduling constraints and legal constraints. Physical resource constraints include the number of patrol cars available, the number of police officers available to operate those cars and the availability of support staff and safety equipment that the police officers need to complete their duties. Economic constraints are presumed to be a function of the budgets available for police officers and support staff salaries, for the purchase of equipment and for the ongoing operation of police activities. Scheduling constraints will likely be imposed by the contracts of the police officers and their union, and by the desire to equitably distribute the workload among the officers who are assigned to the designated police patrol areas. Finally, it is presumed that there are numerous legal constraints on the level of police service that must be provided by the police and that control the areas that they must patrol.

Conclusions, Discussion, and Future Research

Since GIS software is not designed to solve computationally complex problems such as the police patrol area problem, a GIS cannot be used in isolation to find optimal solutions. By integrating GIS with software that is capable of determining optimal solutions to such problems, a system can be built that can take advantage of the strengths of both to create understandable output for decision making once the optimal solution has been found. In this context GIS provides an interface for querying users regarding model instance parameters, and the functionality for pre-processing the geographic data to be submitted to the solution software and post-processing the results of the solution procedure.

Complementing the GIS is the process of developing a mathematical model to represent – as best as is possible – the system within which police patrol areas must be developed. This chapter suggests the PPAC model as an appropriate representation. PPAC seeks to maximize the coverage of crime incidents within an acceptable service distance as defined by the user, and will do so by creating a user-defined number of police patrol areas.

Such an integration of GIS and optimization software has been developed and presented in this chapter. In order to test the ability of covering models to solve the problem of determining optimal police patrol areas, a pilot study was conducted for the city of Dallas, Texas. One of the problem instances was presented here with the results showing an improvement in service distance over the current spatial arrangement.

However, there are many possible improvements to the model and its implementation. First, an ideal interface with GIS would consist of a custom application that could input the updated crime incident locations as they are made available by the police department, as well as variables such as the number of available police officers or special events requiring additional police support. The system could then recompute an optimal solution and transmit the results to patrol areas or to decision makers as image files or geographic data files. Industry standard GIS programs contain all the necessary functionality for the dissemination of the results in this way.

Secondly, although each of the problem instances using the Dallas dataset were able to generate optimal solutions (even with 1167 response areas used to generate 233 beats) the model should be more rigorously tested with larger samples, particularly with larger sets of crime incidents. Moreover, if address-geocoded locations of instances become available they should be used, which would also allow the use of network distances.

The presentation of the PPAC model is not intended to suggest that beat-based patrolling is superior to any other approach for police organization. PPAC is not presented – and should not be interpreted – as an alternative to hot-spot analysis or any other means of determining the concentration of crime locations. Such techniques have proven their usefulness in suggesting intelligent distributions of tactical police resources, including education and crime prevention initiatives (Sherman, Gartin & Buerger, 1989). PPAC is simply a model that can be used to present alternative spatial partitionings of existing administrative or patrol boundaries to decision makers. PPAC generates optimal solutions to the problem of covering crime locations given an acceptable service distance specified by the user. Given that such boundaries exist in virtually all metropolitan police departments, alternatives allow for improved efficiencies in the deployment of limited police resources. Even recent comparative analyses of crime patterns suggest that current research could benefit from the development of alternative geographic frameworks for analysis (Craglia et al., 2000)

The solution of these models has several implications for policy and practice. By using an optimally determined set of patrol areas, police departments can better serve the population and use their resources more efficiently. If these patrol areas can be changed rapidly through repeated solution of the PPAC model under changing conditions, the police department can more readily respond to these changes. Moreover, given the many people and organizations who will need to approve the changes suggested by the optimal solutions that are found, the results must be presented as a series of alternatives from which a best arrangement can be selected that will satisfy the greatest number of people and that can be efficiently implemented.

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