Designing guard patrol routes in security estates

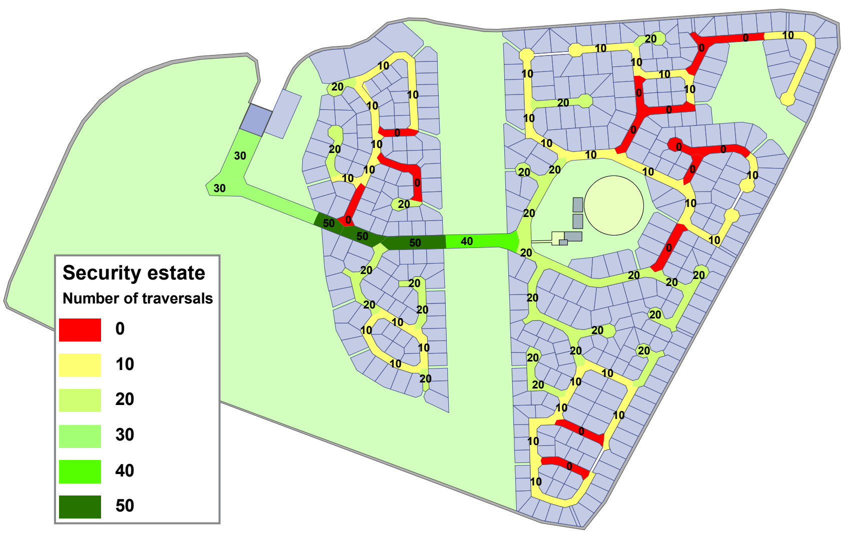
by Elias J Willemse and Dr Johan W Joubert

Gated communities are a growing phenomenon in South Africa, reflecting an attempt by members of the public and developers to counteract the high levels of crime recorded in the country. Of the gated communities, security estates have become a popular choice for residence, mostly because of the estates' ability to provide 24-hour security to their inhabitants.

The security systems of estates are designed using crime prevention through environmental design principles that rely on the ability to influence offenders' decisions before they embark on criminal acts. The security systems' main objective is not to identify and punish criminal activities, but to enhance the perceived risk of detection and apprehension. This approach requires highly visual security initiatives, such as the patrolling of the estates' inner roads and path networks by security guards.

Figure 1 shows a map of a typical security estate. In terms of size, the estate is fairly large and contains 404 properties, a golf course and a cricket ground. Designing patrol routes for such an estate can become extremely complex as a result of the multitude of roads and paths that connect the estate's properties. The patrolling complexity is increased even further when certain essential conditions are taken into consideration: security guards cannot follow the same patrolling route every day, as this predictable routing information could be used by unlawful parties to side-step the security guards. Moreover, all roads and paths have to be patrolled evenly as information regarding lesser patrolled roads and paths can be exploited. Patrolling of the roads and paths should also be evenly distributed among the guards to avoid discontentment and possible work overload.

During the analysis of the patrol routes of the estate in Figure 1, certain major deficiencies were identified. The three current patrolling routes result in a number of road segments not being patrolled at all, as indicated by the red sections in the figure. In contrast, other segments were overpatrolled as much as fifty times during a day, indicated in the figure by the dark green sections. On the other hand, Figure 2 indicates the patrol routes generated by using a metaheuristic optimisation algorithm the researchers developed. The routes generated by the algorithm result in the even patrolling of the estate, while also ensuring even work distribution among the guards. A measure of unpredictable patrolling was also successfully introduced by using the algorithm.



→ *1. Original patrolling density of estate.*

To generate patrol routes for the security estate, the three-phased operations research process was followed, according to which a problem is identified, modelled and solved, based on the model.

The problem that was identified was: "how does one design patrol routes for security guards who have to patrol a security estate?" In the second phase, the problem was modelled, i.e. simplified or reduced, so that it consisted of only its most important and relevant components.

When designing patrol routes, researchers are more interested in the actual road network of the estate. They are not really that interested in the individual properties. Accordingly, the estate of Figure 1 can be reduced to a series of nodes and edges representing the estate's road network (Figure 3). Each node represents a road intersection or dead-end. Further, each arc represents a street segment connected by two nodes. Solid lines represent roads that contain properties and these have to be patrolled. The dotted lines represent roads, or rather paths that do not have to be patrolled, but may still be followed by the guards to move to and from the solid lines.

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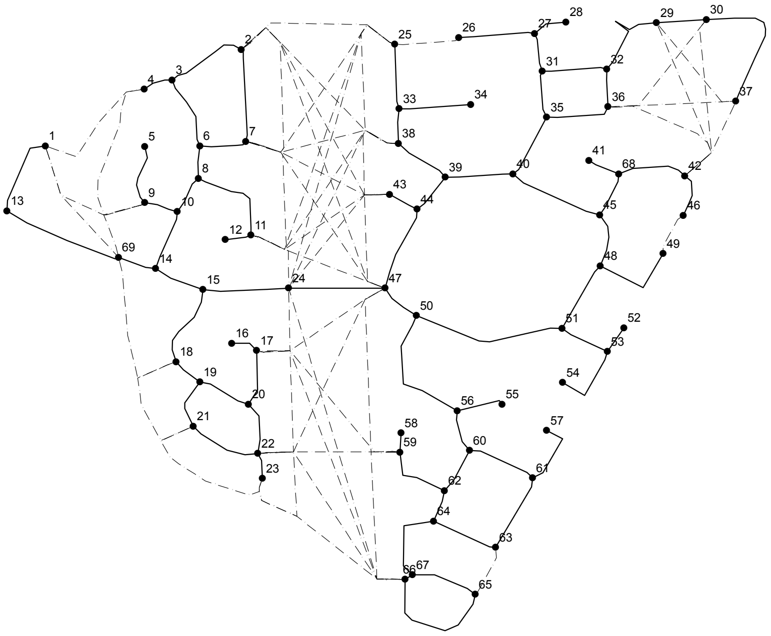
→ *2. Number of street traversals through 24-hour patrolling for three guards with the new patrol routes.*

Given the reduction of Figure 1 to Figure 3, the patrol route design problem is pretty straightforward. Let us assume there are three guards. Each guard route is represented as a list of nodes that a guard should visit in sequence, and each route should start and end at the guard house (node 1). The aim is to design the three routes so that all solid lines are traversed at least once by one of the guards. Also, to avoid work overload, the distance travelled by the guards should be minimised, but the three routes should also be more or less the same length. This type of problem is referred to as an arc routing problem, with arc being synonymous to edge. The specific problem is a min-max type problem. The longest of the three patrol routes (maximum route) should be as short as possible (minimised). The min-max objective is ideal when each edge has to be served as early as possible and when more balanced routes are required.

After modelling the problem, the researchers moved to the next and final phase of the operations research process: solving the problem based on the model. As shown, the guard patrol route problem is simple to model, but surprisingly difficult to solve. In fact, the problem belongs to a class of problems termed NP-hard. In essence, this means that there is little chance of finding an optimal solution to the problem using exact optimisation techniques such as integer linear programming: it would simply take too long.

NP-hard problems are best solved using heuristic methods, also called approximate solution algorithms that produce good enough solutions. Heuristics are able to create feasible solutions within reasonable computing time. They start by generating an initial solution using a rule-of-thumb approach that humans would typically use to solve the same problem. Heuristics then iteratively improve the solution until no more improvement is possible. Though the final solution is feasible, and thus solves the modelled problem, it is usually not very good, which is where metaheuristic solution strategies come into play.

Metaheuristic algorithms incorporate heuristics, but instead of stopping when no more improvement is possible, they simply proceed and make the solution worse. The algorithm then



→ *3. Network representation of Midfield Estate.*

tries to improve this 'worse' solution, leading to a different and sometimes better final solution. This worsening and improving cycle may repeat for as long as necessary. By making the solutions worse in the short term, metaheuristics are capable of finding significantly better solutions in the long term. Currently metaheuristics are the most successful solution strategies for NP-hard problems.

The metaheuristic algorithm that was developed to generate patrol routes is based on tabu search. The algorithm uses memory structures to record characteristics of changes (improvements and non-improvements) that it makes to a solution. It then uses this memory to avoid undoing changes recently made, again similar to how a human would solve the problem.

So how do the solutions generated by the tabu search algorithm compare to current routes implemented at the estate? It was already shown how the patrol routes result in the whole estate being patrolled evenly (Figure 2). In terms of a balanced work distribution among the guards, the difference between the longest and shortest of the algorithm's routes is only 74 m, compared to 1 011 m with the current routes. Lastly, the current patrol routes are too predictable and inflexible, since the same three patrol routes are being followed every shift. The routes assume that there are always exactly three guards available. Management indicated that guard availability varies per shift from two to six guards. The tabu search algorithm generated 30 high-quality solutions, five solutions for each realisation of the number of guards available.

Depending on the guard availability, the security manager can then randomly choose which of the five patrol route combinations to implement, the sequence in which they are implemented, and which of the patrol routes should be followed in a clockwise or counterclockwise direction.

In summary, patrolling according to the new routes generated by the tabu search algorithm is much more unpredictable and flexible. The new routes result in the even patrolling of the estate and an even work balance among the guards. Guard patrolling for the estate, and any estate in South Africa for that matter, will never be the same again.

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