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How Officers Create Guardianship: An Agent-based Model of Policing

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Abstract

Crime is a complex phenomenon, emerging from the interactions of offenders, victims, and their environment, and in particular from the presence or absence of capable guardians. Researchers have historically struggled to understand how police officers create guardianship. This presents a challenge because, in order to understand how to advise the police, researchers must have an understanding of how the current system works. The work presents an agent-based model that simulates the movement of police vehicles, using a record of real calls for service and real levels of police staffing in spatially explicit environments to emulate the demands on the police force. The GPS traces of the simulated officers are compared with real officer movement GPS data in order to assess the quality of the generated movement patterns. The model represents an improvement on existing standards of police simulation, and points the way toward more nuanced understandings of how police officers influence the criminological environment.

1 Introduction

The term *guardianship* is a criminological concept that refers to the way guardians, such as property owners and the police, prevent potential offenders from committing crimes (Cohen and Felson 1979). When potential offenders are choosing whether to commit a crime, they consider how likely they are to be apprehended or stopped by fellow citizens or police officers in their immediate area (Kleck and Barnes 2008). The offender's choice to offend is therefore based in part on his or her interactions with other people, and in turn the higher-level crime patterns that emerge from the choices of all of the individual offenders are influenced by the physical presence (or absence) of police and citizens. Given these complex interactions, police forces seeking to influence local crime rates must understand how their officers' presence and movements influence their environment.

However, the way police create guardianship is not obvious, in part because it is complicated by the realities of modern policing. Policing is a complex, culturally specific process, and officers have many intersecting responsibilities (Police Studies Institute 1996). While Robert Peel identified the prevention of crime and disorder as the first goal of policing (Home Office 2012), police forces are also asked to help with finding missing persons, providing security at public festivals, and handling traffic accidents (Metropolitan Police 2014b). Each of these responsibilities is a substantial burden on the time of officers, and the guardianship they create with their physical presence is constrained by the demands of their assignments. Police officers

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must attempt to prevent crime while also dealing with other demands on their time, and must create guardianship as part of the greater context of their work. This balancing act is especially difficult in light of recent cuts to operational budgets that have required police forces to use fewer officers but handle the same workload (Home Office 2011; Wilson and Weiss 2014). For researchers attempting to influence crime rates by suggesting police policy, ignorance of the way these limitations constrain officer presence and movement will result in policy suggestions divorced from reality.

Researchers have historically failed to handle these complications in their models of policing and guardianship. Some efforts have explored the way policies that aim to influence guardianship actually impact offender behavior: for example, MacDonald (2002) used a mathematical model to explore how proactive, community-oriented policing influenced rates of reported crime. Similarly, researchers have studied how the presence of police or homeowners influence reported crime rates (e.g. Koper 1995; D'Alessio et al. 2012). While these models explore the effect of guardianship, they do not explain how it is created. In general, researchers face two problems in trying to understand guardianship: first, many methodologies cannot capture the behavior of a system comprised of many interacting individuals, and second an absence of data that could support such a model.

Given the importance of accurately capturing the dynamics of policing, the simplifications many researchers have introduced into existing models are so radical that the models omit critical processes. A number of simulations emulate the process of officers carrying out responsibilities as part of a larger group, but ignore the many complicating factors, such as the purposeful movement of officers and the fact that they have other responsibilities: for example, Birks et al. (2012) simulate both officers and offenders moving about an environment at random, with the former arresting the latter whenever they meet. The work of Groff (2007) similarly assumes random police movement. Typically, officers also go about their business without interruption, solely dedicated to deterring the specific crime type being studied. Pitcher (2010) puts forward a mathematical model of guardianship in the context of burglary, but officers move exclusively in response to the density of burglaries. Further, simulated officers are unimpeded by the time-consuming process of actually dealing with offenders. In the work of Melo et al. (2006), police officers patrol specific beats without interruption; police teams interrupt crimes simply by existing, without needing to expend time or to coordinate with one another to take the offender into custody. Similarly, the work of Dray et al (2008) explores the practice of targeting police presence, but their simulated police officers are exclusively dedicated to patrolling, incurring no cost or distraction when they make arrests. These simplifications significantly bias officer movement patterns, generating patterns of guardianship that do not match the guardianship created by real officers.

In all of these cases, researchers have been hampered by a lack of access to information about officer duties, incapable of incorporating the complexities of policing into their simulations for want of data. As shown, throughout the existing literature officers move randomly or fail to expend time on their responsibilities, preventing models from exploring the dynamics of real policing. These simplifications are a necessity for researchers without access to data about the multitude of demands upon officers, but richer and more meaningful models of police activity are possible when information about police responsibilities is available. As a result of our working relationship with the London Metropolitan Police, we have access to this kind of information in a research environment, and we can build such a model. Developing a model of how individual police officers help create this guardianship environment will make it possible to explore the patterns of crime that arise in counterfactual worlds in which police officers are tasked or positioned differently, and with our rich datasets we can more effectively influence policy.

This work presents a simulation which seeks to capture the complex realities of policing, using a combination of data and behavioral field research to create a realistic model of police activity. Given that policing is complex, spatio-temporally informed, and profoundly influenced by human decision-making, we utilize an agent-based model (ABM). Specifically, the model presented in this work utilizes an agent-based framework to explore how officers translate their assignments into movement and actions in the context of the environment in which they find themselves. Agent-based modeling is a type of simulation that seeks to capture how individual units – "agents" – interact with their surroundings and with one another, allowing higher-order behaviors and structures to emerge from these interactions (Epstein and Axtell 1996). In an ABM, an ***agent*** can represent any unit that is capable of behavior (e.g. a person, a vehicle, a household), and often many different kinds of agent may exist in the same simulation. Agents are situated within surroundings that influence and constrain their behaviors: these may include spatial spaces such as road networks or social spaces that define relationships between agents, and are known as the simulation's ***environment***. As a methodology, ABM has been applied to explore questions in fields including archaeology, economics, ecology, geography, and political science, among many others (Crooks and Castle 2012). The exploration of human behavior as it is informed by a variety of data sources is an emerging field of research (Watts 2013), and represents a promising new tool for exploring complex and important processes. It has been particularly successful in incorporating criminological concepts such as routine activity theory (Cohen and Felson 1979), rational choice theory (Cornish and Clarke 1987), and crime pattern theory (Brantingham and Brantingham 1984) into simulations (e.g. Groff 2006; Birks et al. 2012; Malleson et al. 2010).

ABMs allow for spatially explicit individuals to move, perceive, observe, and decide on courses of action based on their surroundings and personal characteristics, permitting simulations to capture all of these variables (Heppenstall et al. 2012). Thanks to the data provided to us by the Metropolitan Police (Met Police), we are able to factor the myriad responsibilities and roles of the police into our simulation, giving a more accurate picture of the environment in which police are attempting to carry out their responsibilities. The ability to contextualize human perceptions, decisions, and agency in different kinds of environments makes ABM an ideal candidate to apply to situations in which human behavior influences the system (Weinberger 2011), and a model that emulates the behaviors of individual officers can give insight into how changing the environment or the officer's roles might influence policing outcomes. Thus, ABM allows researchers to explore counterfactual situations, comparing the projected effectiveness of different interventions or actions (Wise 2014). These counterfactual explorations based in behavior are inaccessible to other methodologies, and make our model more powerful and applicable to the needs of the Met.

The remainder of this article is structured as follows: Section 2 will present a brief overview of the policing context and behaviors we seek to emulate in our simulation. Next, Section 3 explains the methodology being utilized in this article, and will present the model as constructed. Section 4 will apply the model to a case study involving the London borough of Camden, verifying and validating the model against GPS traces taken from real-world Met Police officers. Finally, Section 5 will address conclusions and present an overview of future work.

2 Policing Context

The culture of policing varies dramatically among countries, regions, and even neighborhoods. Officers carry out different responsibilities and interact with citizens in very different ways depending on the local context. Our work deals specifically with the Metropolitan Police in London, whose stated goals are "to make London the safest major city in the world" and "to cut crime, cut costs, and continue to develop the culture of the organization" (Metropolitan Police 2014a). The Met's responsibilities broadly include everything from investigating homicides to preventing terrorism to directing traffic, depending on the situation (Metropolitan Police 2014b). While many specialized task forces exist as a part of the Met Police, in this work we focus on the activities of regular police constables and community support officers, who are some of the most visible projections of guardianship into the communities they serve and about whose movements we have excellent data. Section 2.1 will present an overview of the structure of a police constable's day, while Section 2.2 will present a formalization of this structure broken down by the roles our simulated officers may be assigned.

2.1 Structure of a Shift

Based on interviews with current and former Met Police officers, police constables experience their on-duty shifts as follows. First, an officer's shift begins with a briefing from the duty officer. During the briefing, officers will be given high-level tasks for the shift. Some of these tasks have to do with carrying out specific roles, such as guarding a prisoner in a hospital. Other tasks are more abstract or reactive, such as maintaining visibility in certain neighborhoods or being on the lookout for specific types of crime (e.g. officers will seek to prevent the continuation of a series of car thefts). Individual officers may be asked to balance a number of goals all at once, all while carrying out the more explicit, role-based assignments throughout the day. The specific instructions given during the briefing can vary from station to station and even from shift to shift – different duty officers will tend to emphasize different responsibilities and priorities depending on their own assessment of importance and the particular pressures on the department at the time.

Once the briefing is over, if the officer is assigned a vehicle, he will acquire the vehicle and carry out a car check. Subsequently, the officer will assume his duties, perhaps responding to urgent calls for service, patrolling an area, or staffing the report car, which carries out meetings with people who need to speak with police officers but are not in urgent need of assistance. Officers may be assigned to patrol certain areas during their downtime, but downtime is often scarce: an officer might be pulled from patrolling in order to help direct traffic around a car crash or to search for a vulnerable missing person. This changing of responsibilities is an important aspect of police activity, and can prevent officers from pursuing other crime prevention goals such as patrolling hotspots.

If a call for urgent service comes into the Met Police command and control centre, the Despatcher will contact the officer nearest to the site of the incident and, if the officer is not dealing with another task already, redirect the officer to deal with the incident. If an officer needs to transport a suspect back to custody and cannot do so himself, he will call up Despatching and ask for a vehicle with the capability to transfer the suspect to be sent to the area; the officer then waits with the suspect until the transport vehicle arrives and the transfer is made. In some cases, officers must return to the station to file reports, such as those associated with the suspects they have apprehended. An officer who has responded to an incident resumes his other duties and becomes available for further tasking. At the end of the shift, officers must write up reports on the incidents to which they responded during the course of their duties. Responding to calls, managing crime scenes or searches for missing persons, coordinating with others, and filling out paperwork are important but time-consuming aspects of the job, and these constrain the amount of time an officer can spend carrying out explicitly crime prevention-oriented activities.

It is important to emphasize that as a part of this structure, officers are influenced by one another and by their surroundings. Because officers are assigned to respond to urgent incidents based on who is the closest, the locations of police officers relative to one another can significantly influence response time. The speed at which a patrolling officer can drive is determined by traffic lights and traffic, and thus officers make route choices informed by the transportation system. The spatial and collaborative aspects of policing influence how officers create guardianship in a complex system with many feedbacks. Further, for reasons of jurisdiction officers are unlikely to carry out patrol activities outside of their borough, so that these processes are generally taking place within a well-defined space and time.

These complexities present challenges to most methodologies. The spatial nature of the processes inhibit the use of mathematical models, while pure geographic information system (GIS) techniques or network analysis methods cannot incorporate the heterogeneous and varying nature of officer assignments. Further, all of these aspects of the process interpenetrate and influence one another in complex, path-dependent feedback loops. The problem of determining guardianship therefore requires a spatio-temporally explicit methodology which can incorporate behaviorally heterogeneous individuals, a task to which ABM is especially suited. The next section will present a proposed structure for officer behavior that captures these interacting dynamics, a structure that will be operationalized in the ABM presented in Section 3.

2.2 Formalization of Officer Behavior

To investigate how an officer's diverse responsibilities translate into officer movement and presence, it is necessary to develop a formalized model of officer behavior. Drawing upon the daily structure described in the previous section, we created a generalized shift structure common to all officers. Additionally, we identify a specific set of "roles" for officers, which correspond to the assignments the officers receive as part of their morning briefing and dictate the actions an officer should take to achieve his assigned goals. During the course of a shift, an officer can be assigned a new role, allowing the police force to respond to the demands upon it in a dynamic fashion.

In this work we will investigate the activities of regular police constables who have been assigned vehicles as a part of their roles. This selection was made because we have a rich GPS dataset tracking vehicle movement over the target period, allowing us to compare our modeled output paths with the real paths; this dataset will be discussed further in Section 4. As we are tracking vehicles rather than individual officers, elements of the officer's day such as the morning briefing and the car check are collapsed into the processing of the vehicle between shifts. The formalization of the structure of a vehicle's shift is shown in Figure 1. During the shift, the vehicle is constantly querying its personal role in order to determine what its next action should be.

Each personal role is further formalized and presented as a flowchart in Figures 2–4. The set of roles we consider here are drawn from our interviews, and are broken down into three categories: officers may be assigned to ***responding*** to calls, managing a ***reporting*** car, or driving a ***transport*** van. A vehicle that is responsible for ***reporting*** attends to extended calls for service, traveling according to normal laws of traffic and spending time at each stop (see Figure 2). When reporting vehicles have no other assignment, they patrol the area until they are called up again. ***Transporting*** vans are responsible for transporting either suspects or officers, and are therefore dedicated to moving between incident sites and police stations; they also obey normal laws of traffic (see Figure 3). ***Responding*** vehicles are primarily responsible for dealing with

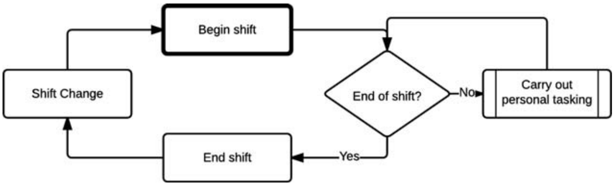

Figure 1 Flowchart of Vehicle behaviour. The thick border indicates the state in which the Vehicle initializes, the rectangular containers represent actions, and the diamond containers indicate decisions

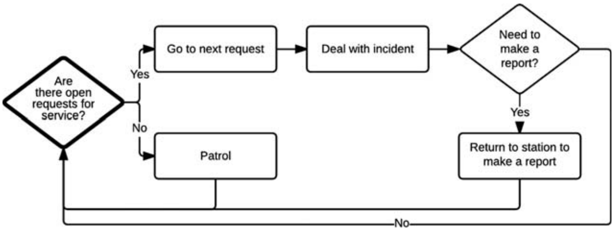

Figure 2 Flowchart of Reporting role. The thick border indicates the state in which the Vehicle initializes, the rectangular containers represent actions, and the diamond containers indicate decisions

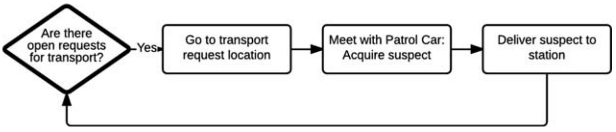

Figure 3 Flowchart of Transport role. The thick border indicates the state in which the Vehicle initializes, the rectangular containers represent actions, and the diamond containers indicate decisions

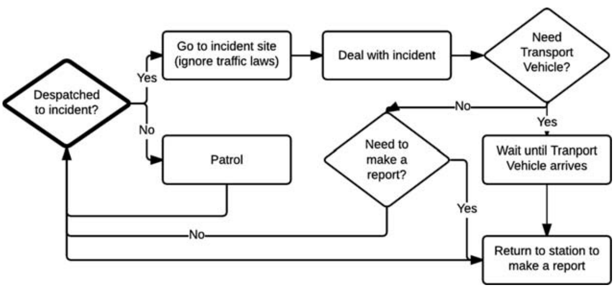

Figure 4 Flowchart of Responding role. The thick border indicates the state in which the Vehicle initializes, the rectangular containers represent actions, and the diamond containers indicate decisions

urgent calls for service; in between these responses, they patrol around certain targeted areas according to traffic laws (see Figure 4).

The simulation presented in the next section employs the officer formalization presented here in order to explore how officers interact with one another and with their surroundings. By utilizing the officer behaviors presented here, the simulation represents a step toward a more nuanced representation of policing.

3 Methodology

In this work, the model attempts to capture the behaviors of Metropolitan Police constables as formalized in Section 2, simulating the system at the level of the movement of police vehicles throughout the day. Individual vehicles are assigned to “roles”, or types of duty including being a reporting car, a transport van, or a responding car. Based on these assignments, they move through a road network, responding to calls for service at different points on the network based on their current assignments. The work presented here both addresses the lack of nuanced simulations of policing and pushes forward the practice of using real-world data in simulations in order to emulate rich environments for behaviorally complex agents. The model framework is built in Java, using the MASON simulation toolkit, an open-source multiagent simulation library (Sullivan et al. 2010). The simulation models the roads and officer movement at $1\,m^2$ resolution, and is updated on a temporal scale of one minute per simulation step. The code for the simulation as well as the pre- and post-processing of the relevant data is available on GitHub, although the data that supports the analysis presented here are sensitive and not included in that repository (see https://github.com/swise5/ModelOfficer). The following sections will describe the environment in which the vehicles exist, the way vehicles are represented in the simulation, and the way vehicle behaviors are translated into actions according to the formalization presented in Section 2.2.

3.1 The Environment

In order to represent the environment in which police vehicles are acting, the model combines information about the real-world road network with records of calls for service from the community. The road network is drawn from the Ordnance Survey MasterMap Integrated Transport Network Road (ITN) dataset, buffered around the area of Camden at a distance of 100 m to avoid edge effects. The network is partitioned into individual road segments, so that the use of one particular segment of road is not conflated with other parts of the road. The locations of police stations, which factor into the activities of the police vehicles, are taken from the data provided to us by the Met Police. The locations of traffic lights, which impose a time cost on the movements of officers throughout the environment, is taken from data provided by Transport for London (TfL).

In addition to the physical constraints of the environment, vehicles are influenced in how they move by the calls for service that they receive from the general public. The simulation takes as input a file indicating when and where officers are asked to attend to calls for service, as well as how urgently they need to respond – graded “immediately”, “soonest”, or “extended” (I, S, or E). For example, in this analysis, the set of real records from the Met Police’s Call Aided Despatch (CAD) system during the month of March 2011 are used to create calls for service in the simulation. In this way, the pressures and constraints upon the officers are rendered in a simulated setting.

Table 1 Vehicle attributes

Attribute	Possible Values	Example Value
Current Location	Point in space	(3487, 2387)
Home Station	Point in space	(3487, 2387)
Call Sign	String	EK8N
Role	Role Object	Response Role
Current Activity	Patrolling, Occupied, On Way to Role, On Way to Station, Waiting	Patrolling
Current Status	Off Duty, Occupied, Meal Break, Available	Available

3.2 Vehicles

As indicated in previous sections, the model represents the actions of police officers in terms of the movement and interactions of police vehicles. Vehicle agents have attributes that inform their actions. Table 1 provides an overview of the attributes that characterize the Vehicle agent at any given point in time, specifying the range of values these attributes may take on and providing examples of such values. In particular, Vehicles have a current `location` in space, a home `station`, a unique `call sign`, a `current activity`, and a current `status`, as well as a `Role` object, which will be discussed further in the section on Vehicle behaviors.

The Vehicle's `current activity` at any point in time characterizes its activity during that time step: it is an indicator that helps to structure the way the agent determines its appropriate next activity. The Vehicle's `status` indicates whether they are available to be assigned to respond to an urgent call for service. The available `status` values are: *off duty*, *occupied with tasking*, and *available to be reassigned*. The set of possible `current activities` consists of *patrolling an area*, *dealing with a specific activity*, *waiting*, and *traveling to the station* or to a *location* associated with an assignment. The `status` option is the simulation equivalent of the real-world officer's radio setting, which communicates to Despatch whether the officer is available to respond to calls for service, while the `current activity` represents the precise actions the officer may be undertaking. Vehicles can be assigned to carry out one of a number of `Roles`, which will be discussed further in the section on Vehicle behaviors. During the course of a shift, a vehicle may be assigned a new `Role`, so that a vehicle that was previously assigned to reporting duty might be asked to serve in a transport capacity, or a responding vehicle might be pulled to help with reporting. Finally, Vehicles have maximum and normal speeds (80 and 20 mph, based on estimates of maximum safe driving speed and approximate driving speed in the area).

Metadata about the number of vehicles and the shift times during when they are utilized are used to create a realistic population of Vehicles. The next section discusses how the Vehicles translate their `Roles`, characteristics, locations, and assignments into actions.

3.3 Vehicle Behaviors

The set of Vehicle behaviors is drawn from the formalization of officer activities presented in Section 2.2. Based on their surroundings and roles, Vehicle agents make determinations about what actions they should take. Vehicles have a decision-making flowchart that structures their shift: Figure 1 shows the high-level decision tree that determines how a Vehicle chooses its next activity. While all Vehicles have the common shift structure shown in Figure 1, they also have specific `Roles`: reporting, transporting, or responding. In particular, it is important to note that the Vehicle's `Role` is executed within the context of the overall workday – the "personal role" process in the flowchart redirects to one of the flowcharts in Figures 2–4, depending on how the Vehicle in question has been assigned.

Role - Reporting: Reporting Vehicles respond to "extended" calls (E-grade), which are not urgent but require an officer to attend. If a Reporting Vehicle has no call for service to attend, it will patrol. Reporting vehicles always travel in normal mode.

Role - Transporting: Transporting Vehicles wait at the station until they are assigned to meet up with another Vehicle that has a suspect to be transported back to the station. When they receive an assignment, they travel to the assignment location, confirm the transfer with the waiting Vehicle, and then transport the suspect back to the station. They always travel in normal mode.

Role - Responding: Responding Vehicles respond to the most urgent calls for service (I- and S-grade), moving to the site of the incident in emergency mode. In the course of carrying out its responsibilities, a Response Vehicle may take a suspect into custody and need assistance transporting the suspect back to the station; in this case, the Vehicle will call for a transport van and wait with the suspect until the van arrives. If a Responding Vehicle has no call for service to attend, it will patrol. Other than when responding to urgent calls, Responding vehicles travel in normal mode.

Patrolling: A Vehicle that is patrolling will pick an intersection in the target area at random and then drive to the intersection in normal mode. Once the Vehicle arrives as their patrol destination, it will pick a new random intersection and repeat the process.

Movement: Vehicles plan their movement through the network based on the project time cost associated with an A* path that varies based on whether the Vehicles are required to stop at traffic lights. When a Vehicle moves, it proceeds along its planned path, either progressing at maximum speed (if in emergency mode) or travelling at the normal speed and stopping at each traffic light it encounters for a minute (in normal mode). Vehicles can plan their movement according to their specific circumstances, so that they ignore traffic laws when they are responding to an incident but obey them in other circumstances; that is, vehicles will plan their route depending on whether or not they are subject to the delays of traffic lights, counting the cost of waiting at them into their assessment of the "shortest" path.

Coordination: The actions of the Vehicles must be coordinated, which is carried out by the Despatcher object. The simulated Despatcher assigns the nearest "available"-status responding Vehicle to respond to a call, ensuring that the most urgent call is dealt with first. If no Vehicles are available when a call comes in, the call is entered into a queue that is dealt with in order of first severity and then time of call. If a Responding Vehicle apprehends a suspect during the course of its assignment, the Despatcher object matches up the Responding Vehicle that has apprehended the suspect with a Transporting Vehicle, again selecting the nearest "available"-coded Transporting Vehicle.

In the next section, these behaviors will be combined with the data sources previously introduced in order to investigate a case study that explores the effectiveness of these measures in capturing the patterns of officer movement.

4 Case Study: London Borough of Camden

The case study presented here attempts to simulate the way policing was carried out in the London Borough of Camden during March of 2011. Camden is part of Inner London,

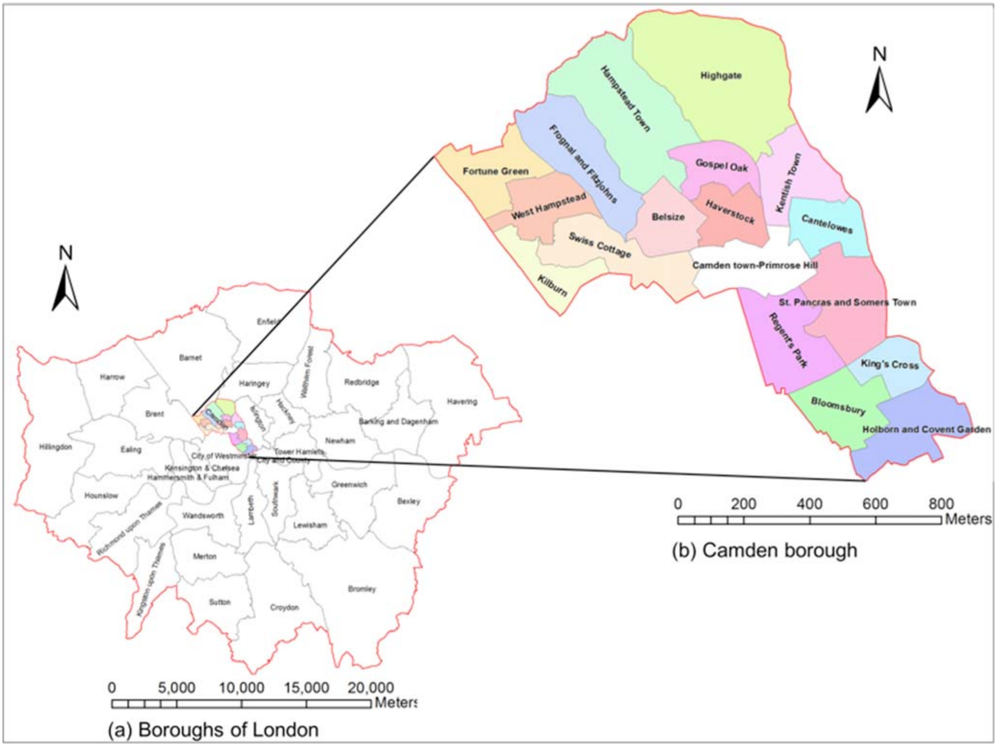

Figure 5 Map of Camden, London

(see Figure 5) and during March of 2011 it had five police stations. As mentioned in Section 3.1, the set of real records from the Met Police's CAD system during the month of March 2011 are used to create calls for service in the simulation; the locations of active police stations are based on the stations of that era. Based on the approximately 19 police vehicles in use per shift in Camden in the historical data, 19 Vehicles are assigned to stations based on station size and needs, as determined from discussions with current and former Met Police officers.

In order to assess the quality of the generated results relative to the data provided by the Met Police, the output of the model is assessed in terms of a heatmap of road usage, the total distance travelled by officers, and a histogram of the frequency of road usage per segment. These measures gives a sense of the frequency with which different roads are used, and can be compared with other road usage data to compare the aggregate patterns of road usage for the entire month without making major assumptions about the trips documented in the real data. The results of the model are compared against GPS traces of the movements of Metropolitan Police vehicles taken from the same period. In order to create the comparison gold standard dataset, the GPS traces were cleaned and snapped to road segments, with individual vehicle paths within the target area being reconstructed in order to form a basis of comparison with the simulated data. The code used to carry out this process is available in the online repository described in Section 3.

To give a sense of how the model compares with existing simulations, we compare our model output with a baseline random model that emulates the behaviors of other models, highlighting the differences between our model and the current norm. This model embodies the assumptions other models make with regard to lack of alternative police responsibilities and constant movement, and reflects the influence that behavior has on aggregate movement patterns.

4.1 Verification

In this article we refer to "verification", the process of ensuring that the implemented model matches the designed model – that is, that the code produced as part of this work correctly carries out the processes described in Section 3 (North and Macal 2007). The process of verification is a necessary step in sharing models, as without verification the generated results may be the result of some peculiarity of the code. Without verification, replication efforts can be confounded, and the scientific value of the work is negligible. Thus, this model was verified through extensive code walkthroughs. By following individual agents, it was possible to ensure that the Vehicles were carrying out shift patterns as designed. To give an example taken from an actual run of the simulation, the activities of one simulated responding Vehicle are as shown in Table 2.

After going on shift and beginning to patrol, the responding car is pulled to deal with an "immediate" (I-grade) call at time 1081. It arrives within a few minutes, deals with the situation, apprehends a suspect, calls in for a transport van, and waits until the van arrives to collect the suspect. Having completed this response, it moves on to responding to the next call it has been assigned. Near the end of the shift at time 1411, the responding Vehicle starts back toward its home station in order to end its shift, but receives a "soonest" (S-grade) call for

Table 2 Segment of response vehicle activity

Minute	Action
975	Response Car 1 – shift change
990	Response Car 1 – car check
990	Response Car 1 – start patrolling
1081	*I-grade Call received from POINT (529605 183143)*
1081	Response Car 1 – tasked to (529605.0, 183143.0)
1083	Response Car 1 – deal with incident
1107	Response Car 1 – request transport
1126	Response Car 1 – interface with Transport Van 1
1140	*I-grade Call received from POINT (529379 181873)*
1140	Response Car 1 – tasked to (529379.0, 181873.0)
	. . .
1391	Response Car 1 – start patrolling
1411	Response Car 1 – return to station
1441	*S-grade Call received from POINT (529142 182144)*
1441	Response Car 1 – tasked to (529142.0, 182144.0)
1443	Response Car 1 – deal with incident
1453	Response Car 1 – return to station
1470	Response Car 1 – shift change

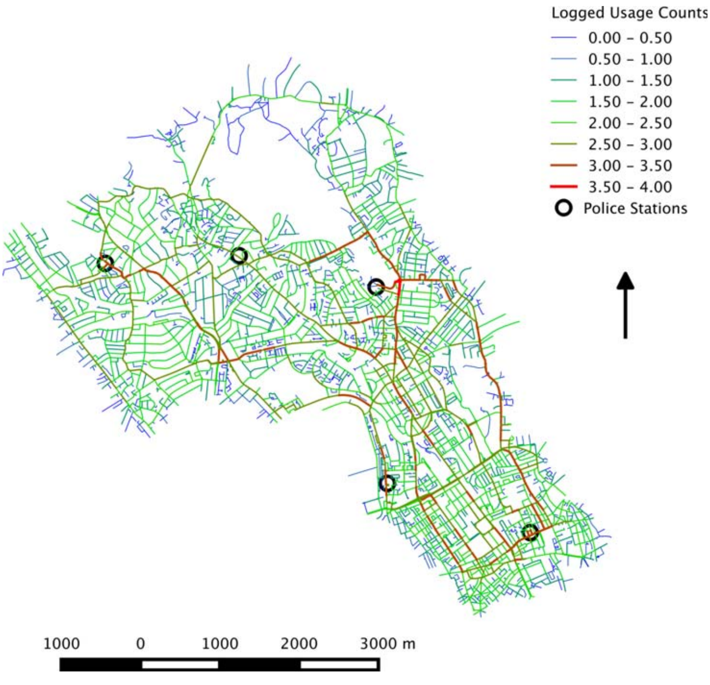

Figure 6 Heatmap of road usage patterns of real officers in Camden. The usage counts represent the number of times officers have utilized a road segment over the course of the one-month period

service on its way back. It responds, and then returns to the station in order to allow for the change of shift. By carrying out similar inspections of the actions and interactions of the different types of Vehicles, it is possible to verify that the simulated Vehicles are carrying out their responsibilities as designed and described in Section 3.4.

4.2 Validation

Having established that the model functions as designed, the next step is to determine whether the modeled processes produce results that resemble the real data; this process is known as validation (North and Macal 2007). In order to assess the quality of the overall generated patterns of road usage, a heatmap of the GPS traces of Met Police officer movement data from March of 2011 was generated (see Figure 6). The heatmap shows road usage by officers, measuring the logged total number of times a road segment is utilized over the course of the month-long study period. The log of the number of times a road is utilized is employed in the visualization because the number of road usage instances per road is approximately log-normally distributed in the real data (as will be shown later in this section in conjunction with Figure 9). This metric for measuring road usage captures the aggregate movement patterns of the force during March 2011, allowing us to assess the road-specific movements of a relatively small number of agents.

As described in the introduction to this section, we have created two models to determine the impact that the full suite of officer behaviors has on movement; here, we compare the full behavioral vehicles against a set of vehicles that move randomly around the environment.

These random agents are identical to our agents in every way except that rather than responding to calls for service, they randomly patrol the road network for the duration of their shifts. This model allows us to highlight the influence that our generated, behavioral methods have on agent movement, distinguishing our work from previous simulations of policing. Thus, a comparison between the randomly moving vehicles vs. our generated tasked vehicles can be made based on Figure 7 (random agents) and Figure 8 (tasked agents). Each of the heatmaps visualizes the usage of each road averaged over 10 different runs of the simulation, reflecting the average movement patterns associated with the pattern of policing.

The gold standard shown in Figure 6 reflects the heavy usage of major roads, with particular concentration around the police stations. Many smaller roads are never used at all, and areas that closer inspection shows to be residential see infrequent presence over the course of the month. Overall, however, there are few roads that are visited more than 1,000 times by any member of the police force over the entire month. The simulated officers who are carrying out assignments cover less ground, although their usage patterns similarly concentrate on the major roads near the stations. The most notable discrepancy with the real data is that tasked, simulated officers do not spend as much time in the southern portion of the region, which is in reality a busy retail zone. Further, simulated officers often choose different routes from their real counterparts – opting for one road in the northern park area rather than the other, or avoiding a particular highway along the eastern border of the area. Both the real data and the tasked agents contrast with the random simulated officers, who are very busy indeed. The most obvious difference among the models is the sheer amount of movement by the random simulated officers. Considered a different way, the real officers end up driving approximately 73,413.5 km over the course of the month, for approximately 2,368.2 km driven per day by the force as a whole. Tasked officers travel less than real officers, 51,063.8 km in the month or 1,647.2 km per day. Comparing with these, random officers travel almost three times as much as real officers do, 212,532.5 km in the month or about 6,855.9 km a day. The concern that simulated officers are overly mobile is borne out by the data, and adding officer responsibilities into the simulation obviously improves the situation significantly.

Figure 9 gives us more insight into these patterns of road usage as it quantifies the frequency with which certain roads are utilized. Three histograms representing logged average usage counts of the gold standard, the tasking simulation, and the random simulation can be seen to differ qualitatively, and to allow for easier comparison. The histogram of the tasking simulation is closer to the fairly normal distribution of the real data, being less left skewed than the random simulation.

The question of whether edge effects on the network help explain the deviation between real and simulated road usage arises naturally, and it could be informative to consider whether adding particular highways outside of the buffered study area would further improve the correspondence between the two.

Reviewing each of the measures of comparison, the tasking model is a decided improvement upon the oversaturated random model, but could probably be improved by more meaningful selections of officer patrolling areas and further data about the time commitments associated with different kinds of assignments. Finally, the route selection algorithm used by all of the simulated agents prefers certain shortcuts that are unrealistic; this could be improved upon by substituting new path-planning algorithms into the simulation, a question on which we are already at work. Between the two simulations, the tasking model generates interesting and realistic results, and presents many clear opportunities for improving further.

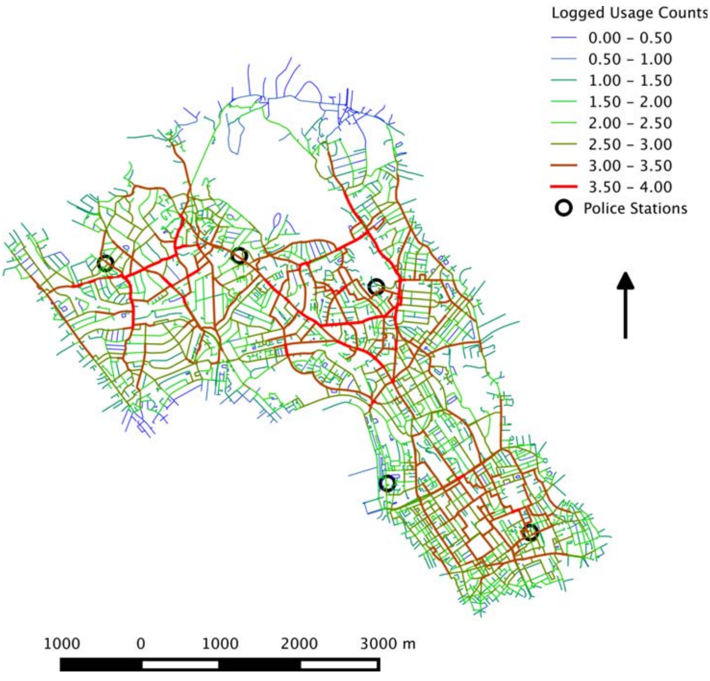

Figure 7 Heatmap of road usage patterns of simulated officers randomly moving around the environment

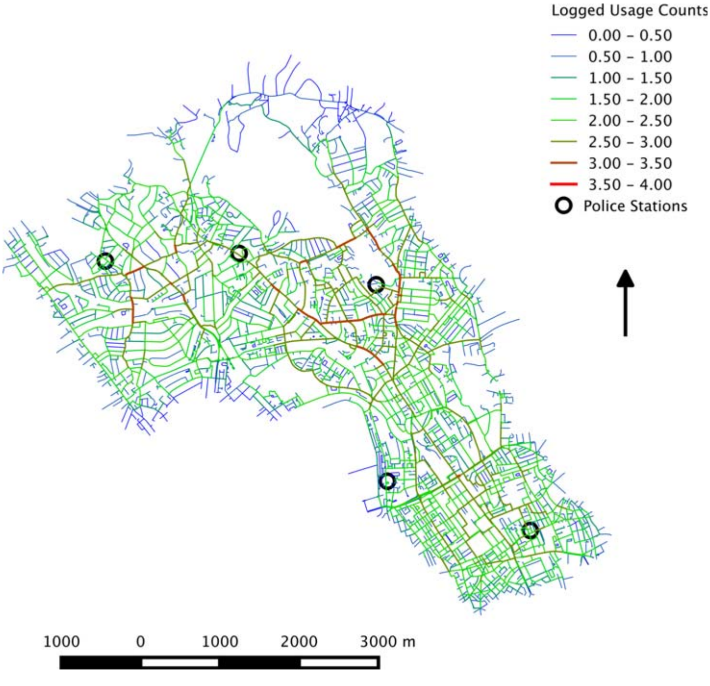

Figure 8 Heatmap of road usage patterns of simulated officers responding to calls for service and obeying assigned responsibilities

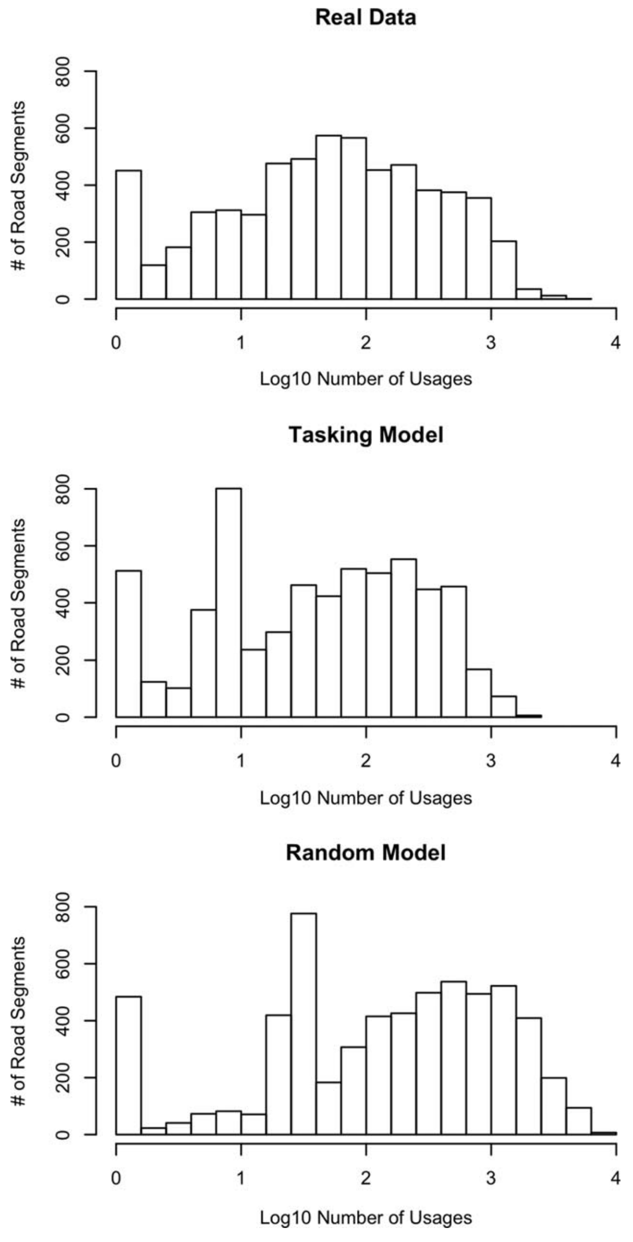

Figure 9 Histograms of logged road usage counts for the real data (gold standard), simulation of random movement, and simulation of officer behaviors

5 Conclusions

Understanding how to create guardianship is both difficult and also important for policing, and existing models of policing fail to capture the way officers move throughout their environments. In an effort to correct this oversight, the model presented here uses empirical GIS data combined with real police incident data in order to simulate a complex, interactive system of police officer movement and behavior, which improves upon the existing uninformed models of movement. The results support the hypothesis that officer responsibilities influence police presence and location in measureable ways, and they highlight the importance of incorporating these aspects of officer responsibilities into models of policing. The use of an agent-based model allows us to simultaneously consider a range of variables in our calculations, and to explore the way police officers interact with and influence one another, creating guardianship in a collaborative fashion. In the future, this investigation of guardianship will allow us to explore how guardianship can be created within different environments, with varying numbers of officers and changing environmental crime rates; further, we will be able to study how varying aspects of officer tasking could be modified to tweak guardianship at a regional level.

Specifically, future work will build upon this model of behavior, confident that we understand and are simulating the relevant dynamics of police activity. In particular, research into more nuanced officer behavioral rules can provide insight into targeting resources; exploring different routing strategies will further this goal. Factoring the influence of time of day and traffic considerations into the path-planning metrics of officers might give insight into how they move through the environment, as could an exploration of officer familiarity with the road network and neighborhoods. Finally, expanding the simulation to explore the entirety of the London Metropolitan area would vastly increase the usefulness of the analysis, and probably eliminate any concerns with regard to the possibility of edge effects. The improvements we have introduced are an important first step into a large field of research.

By exploring officer movement and activity in this way, our future work can also explore how the creation of guardianship influences reported crime rates in the area. This dynamic exploration of officer presence – and the associated risk for potential offenders – will allow us to explore how officers can be positioned and coordinated in order to maximize their effectiveness. Investigations that would be impossible to carry out in the complex, noisy, and high-stakes context of real policing can be ethically and extensively explored *in silico*, allowing researchers to help the police shape their presence and their effectiveness.

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