Mapping Criminal Activity Space

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Abstract

This article discusses how the use of cellular networks by a criminal offender produces spatio-temporal data that reveals his/her activities and activity space. The methods aim to establish possible paths that the criminal will use to move around in his/her activity space; the edges of the activity space; districts in which the criminal is moving such as residential, commercial and industrial areas and attractions such as night clubs and warehouses; and nodes determined by the frequency of cell usage. Using cellular location usage data, it is possible to determine the criminal's mental map of the area in which he/she operates based on routine activity theory approach as well as establishing the criminal's comfort zone. Such information can be valuable for intelligence and investigative purposes.

Keywords: communications analysis, spatio-temporal analysis, routine activity theory, geographic profiling, criminal behavior.

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1. Introduction

Criminals tend to offend close to home and in areas they are familiar with. Behavioral geography and environmental criminology—in particular, crime pattern theory and routine activity theory—provide a framework for understanding and analyzing the geography of crime and the movements of criminal offenders. These concepts provide the basis for geographic profiling, a methodology for determining the most probable area of offender residence from an analysis of his/her crime locations (Rossmo, 2000).

An individual's geographic space is usually generalized by what is known as a mental map. Such maps are influenced by both social and geographic position, as well as an individual's access to different transport modes. For example, an individual who does not own a motor vehicle will usually have a different mental map than a person who does have a motor vehicle. Mental maps are created by the person's awareness and activity space. Awareness space is the space that a person has a general knowledge about and within this awareness space is the person's activity space. The activity space is the area in which a person resides and engages in his/her daily activities such as going to work, shopping, or engaging in recreation such as visiting the gym, movies or pubs. It is comprised of the sites they visit and their travel routes between these sites. Anchor points are the most important sites within an individual's activity space. Typically, this is a person's home, but may include their worksite or school.

Criminals typically offend within their activity space (Brantingham and Brantingham, 1981), though some may commute to other areas for various reasons. In South Africa, the Wemmerpan Serial Killer operated within his "normal" activity space with his residence as the anchor point, whereas the Sasolburg Serial Rapist travelled 30 kilometers (18.6 miles) to his criminal activity space and used a decoy house as his anchor point to trap his victims. The decoy house was located at the edge of an open space.

Crime typically occurs in those areas where offenders' activity spaces intersect locations containing suitable targets or places where victims may be found (train stations, bus stops). An understanding of offender activity spaces is thus important for both practical and theoretical reasons. This paper discusses how the use by criminal offenders of the cellular network produces spatio-temporal data that can reveal their activities and activity space. The methods aims to establish possible paths that the criminal will use to move around in his/her activity space; the edges of the activity space; districts in which the criminal is moving such as residential, commercial and industrial areas and attractions such as night clubs and warehouses; and nodes determined by the frequency of cell usage. Using cellular location usage data, it is possible to determine the criminal's mental map of the area in which he/she operates based on routine activity theory approach as well as establishing the criminal's comfort zone. The approaches on collecting cellular usage information will be discussed in the next section.

2. Two approaches

There are two approaches for determining the criminal activity space of suspect using cellular telephone data. The first approach is to use call data records, which is the recorded use of the cellular telephone when it receives and makes calls, SMS (Short Message Service), MMS (Multimedia Messaging Service) and uses GPRS (General Packet Radio

System). The second method is to actively track the cellular telephone at predetermined time intervals such as every five or ten minutes.

2.1. CALL DATA RECORDS

The cellular service providers break an area up into cells to provide cellular telephone coverage. This is done using a base station (antenna), which is either an omni-directional antenna (an antenna located in approximately the middle of the cell) or a directional antenna (an antenna that transmits into a cell). Figure 1 shows the concept. Hexagons are used for planning purposes, but in reality the shape of the cell is influenced by the terrain (Lee, 1986). Figure 2 gives an example of cells in a small area of Cape Town. Cellular service providers are allocated a specific frequency band in the 900 MHz and 1800 MHz range and use two techniques to enable the service provider to provide a service for millions of subscribers. These two techniques are cell splitting and frequencies re-use (Lee, 1986).

Frequencies re-use is where cells at different geographic locations use the same frequency, but are far enough from each other not to cause interference. Cell splitting is used to break up an existing cell into smaller cells to enable it to handle higher amounts of traffic (Lee, 1986).

Figure 1

Two types of base stations (antennas) used by cellular service providers.

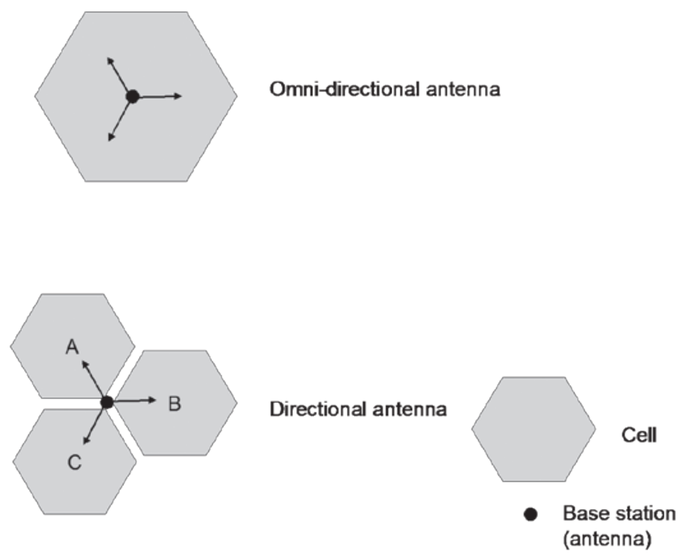


Figure 2

An example of actual cells in the Cape Town area

The switching between different cells based on location

Call data records (CDR) are kept by the cellular service providers to monitor usage of cells as well as for auditing purposes. The service providers keep pre-paid transactions for three months and the contract phone transactions for six months. The Regulation of Interception of Communications and Provision of Communication-related Information Act 70 of 2002 requires from July 2007 that cellular service providers should keep 36 months of CDR for each subscriber. The service providers are allowed to delete any data that is older than 36 months, which means only the 36 months of data is available for analysis (Du Plessis, 2006). The data collected is the date and time of the calls, SMS and MMS made and received, the other party to whom or from whom the calls, SMS and MMS were made or received. If the call has been forwarded to another, the third party's number will be given. The call direction indicates whether a call, SMS and MMS was received or made. If a call was made or received the duration of the call is recorded. When the subscriber uses the cellular telephone to access the Internet or other services through an App, the call data record also indicates the duration and cell used. Internet activity is shown on a CDR as GPRS. The following geographical entities are recorded in a CDR namely:

- Tower (base station) identification number;
- Cell identification number (Cell ID), which consists of the tower identification number followed by a single digit indicating the cell number. If a base station has three cells and the base station identification number is 839, then the cells will be identified by 839**1**, 839**2** and 839**3** (some cellular service add a 0 or 0's before digits as shown in Table 1) or 839-**0**, 839-**1** and 839-**2** based on the convention used by the service provider. The general convention is that the Cell ID with

lowest number (0 or 1) is the antenna that faces North (0°) or closest to North clockwise away from North, the numbering of subsequent cells are done clockwise from the North facing cell (Schepers, 2006);

- A common name given to the base station such ATS or Auckland Park Telkom Ex, which is used by the engineers to find the base station for maintenance purposes;
- The suburb in which the base station is located.

For mapping and modelling purposes, the Cell ID, date, and time are used. The Cell ID is used to determine the frequency of use, which could indicate an anchor point such as the residence, place of work or recreation facility such as a pub, night club or gymnasium. Movement is determined when the Cell ID changes when the next call, SMS or MMS is made or received. The methodology used to determine a coordinate pair for mapping purposes is discussed in Section 3.2.

Table 1

Example of a call data record showing the Cell ID

Date	Time	No.Called	No.Calling	Call.Dir	Call Dur	CELL_ID	TOWER_ID	Site location	Site suburb
15/12/2002	000235	2773228250x	2783765762x	I	52	08393	839	ATS	Millpark
15/12/2002	000400	2783446106x	2773228250x	O	33	08393	839	ATS	Millpark
15/12/2002	000444	2783765762x	2773228250x	O	36	08393	839	ATS	Millpark
15/12/2002	000535	2783446106x	2773228250x	O	43	02772	277	Auckland Park Telkom Ex	AUCKLAND PARK
15/12/2002	001032	2773228250x	2783765762x	I	8	08392	839	ATS	Millpark
15/12/2002	001100	2783446106x	2773228250x	O	21	08393	839	ATS	Millpark
15/12/2002	001931	2783347574x	2773228250x	O	0	08393	839	ATS	Millpark
15/12/2002	001948	2773288063x	2773228250x	O	17	08393	839	ATS	Millpark
15/12/2002	002949	2772392694x	2773228250x	O	26	08393	839	ATS	Millpark

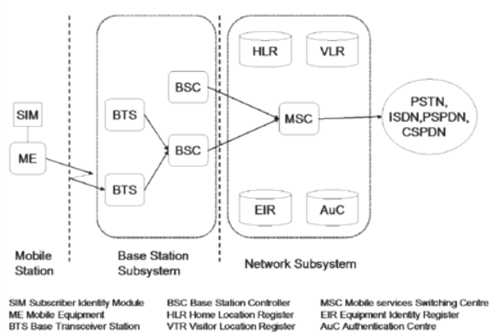
2.2. ACTIVE TRACKING OF THE SUSPECT OVER A SPECIFIED TIME PERIOD

Active tracking of a suspect is done when the suspect is using the network and when his/her cellular telephone is switched on. The cellular telephone system used in South Africa is the GSM (Global System for Mobile communications), which was developed in Europe in the early 1980s (Scourias, 1999). The GSM network can be divided into three broad entities: the mobile station, the base station subsystem that consists of a tower and its associated cells as illustrated in the previous section, and the network subsystem as illustrated in Figure 3 (Scourias, 1999).

The mobile station is the cellphone that a person uses. In a cellphone is a Subscriber Identity Module (SIM) card, which allows the mobile station (MS) access to the cellular network. The base station subsystem consists of two elements, namely the base transceiver station (BTS) [commonly known as a cell tower, base station or antenna] and the base station controller (BSC). The BTS houses the transceivers which define the cell in which a MS can link with the cellular network. The BSC handles the radio resources for one or more BTSs such as radio-channel setup, frequency hopping and handovers

Figure 3

General architecture of a GSM network (from Figure 1, Scourias, 1999)



(Scourias, 1999). The network subsystem consists of the Mobile services Switching Centre (MSC), Home Location Register (HLR), Visiting Location Register (VLR), Equipment Identity Register (EIR) and the Authentication Centre (AuC) (Scourias, 1999). The EIR and AuC are used for authentication and security purposes, which allow the MS to use the cellular network.

The MSC provides the link between the radio network and a fixed line network such as PSTN or ISDN. The MSC also handles the MS such as registration, authentication (links to EIR and AuC), location updating, handovers, and call routing to a MS. The HLR contains all the information about every MS on the network as well as the current location of the MS, which is updated at specific time intervals or when the MS moves into a new cell. The VLR is a subset of the HLR and is used for call control and provision of services for each MS in the geographical region covered by the VLR (Scourias, 1999).

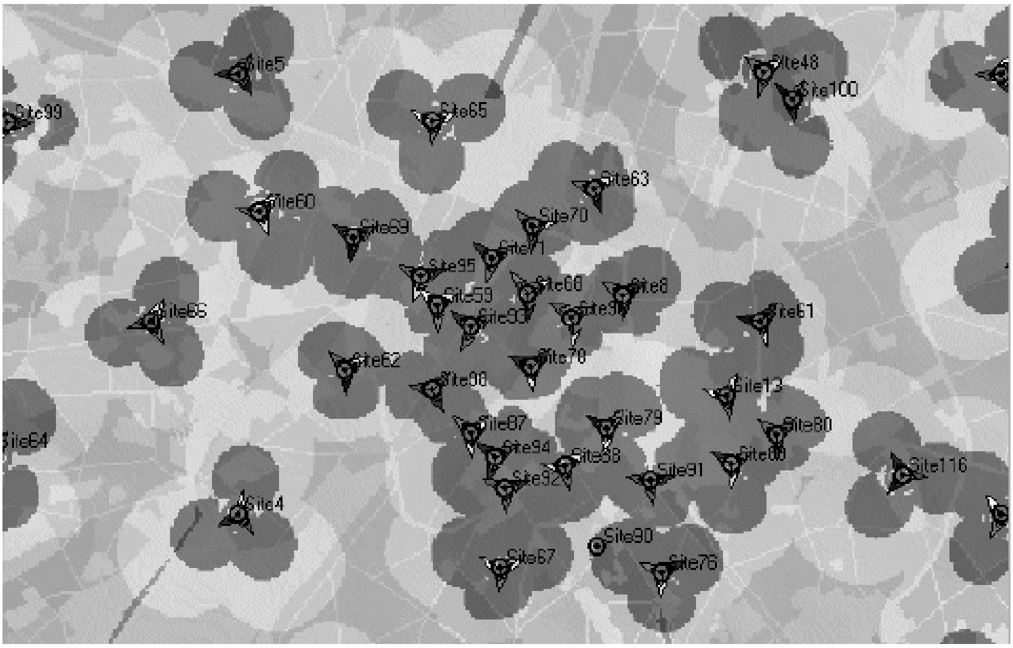
Two bands of frequencies are used, the first band is used to link the cellphone (MS) to the base station (uplink) and the second band is used to link the base station to the cellphone (downlink). Each band is again divided into two channels namely the traffic channel, which allows for speech and data (SMS, MMS, etc.) and the control channel is used by the cellular service provider to manage the cellphones (MS) on their networks. The control channel is used first to locate the cellphone and once the cellphone has been authenticated, the traffic channel opens to allow for speech and data (Scourias, 1999).

To enable the tracking of a cellphone for the purpose of the study, the cellphone must be powered on. The cellular service provider sends a blind SMS (Short Message Service) to the cellphone. The cellphone is informed of the incoming SMS on the control channel using the HLR, VLR and MSC. Once the MSC located the cellphone via the BSC in a cell of a BTS, using information from the HLR, VLR, and the traffic channel is made available for the data to be sent. With a blind SMS, the SMS is stopped just before the traffic channel is made available. The control channel provided the location of the cellphone giving the Cell ID, which is then linked to a coordinate pair along with the subscriber number, time and date (Scourias, 1999 and Abouchabki, 2005). For the purpose of this project, a blind SMS is referred to as a "ping;" and sending a blind SMS is known as "pinging."

Cells in a cellular network are determined by using radio frequency propagation models. These models take into account the characteristics of the selected antenna; the terrain in which the various base stations and its antennas are located; the land use, such as residential, commercial or industrial as well as land clutter such trees, buildings and other obstacles close to an antenna to model the radio propagation from the selected antennas (Khan, 2011). Figure 4 shows the result of such a radio frequency propagation model. The cells are created by determining the boundary between two antennas where the signal strength between the two antennas are the same as illustrated in Figure 2 above. The centroid of each cell was used as a reference location to position the cellular telephone in geographic space.

Figure 4

Determining cells using signal strength (Figure 1, Khan (2011))



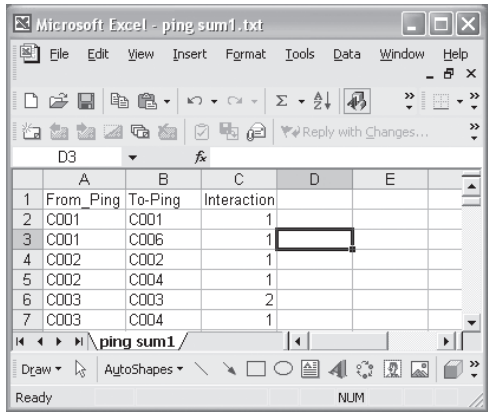
3. Snapping interactions between cells to nearest road network

This section gives an overview on snapping the interactions (movement) between cells based on date and time as well as the Cell ID. If the next call, SMS or MMS made or received or GPRS activity registers a different Cell ID on the CDR than the previous record, the person has moved from the one cell to the next. This is known for the purpose of this project as an interaction. The same principle holds when a person's handset is actively tracked. If the next ping registers a different Cell ID then the person's handset has moved from one cell to the next. The active tracking data will only provide a coordinate pair for each ping. A Cell ID needs to be generated for each coordinate. With the CDR data the Cell ID is given by the cellular service provider and they need to provide the coordinate pair for each Cell ID. This can be done using a court order.

Using the date-time data, the next ping location can be determined. This information needs to be captured in the data set as *FromPing* and *ToPing*. For snapping the interaction to the nearest road network the Cell ID in the *FromPing* column must be different to Cell ID in the *ToPing* column (see Figure 5). If the *FromPing* Cell ID is the same as the *ToPing* Cell ID it indicates that the handset was stationary and will be omitted from the snapping exercise. The stationary data will be used to indicate anchor points based on the frequency of use (counts).

Using the data in Figure 5 as an example, one movement (interaction) has been recorded between C001 and C006, but C003 indicates that the handset was stationary for two consecutive pings. If the number of interactions were seven for C001 and C006, then it means that the handset has moved seven times between these two cells during the tracking period or study period when using CDR data. When snapped to nearest road network, the assumption is made that the person(s) using the handset has used that section of the road network, to which the snapping was made, seven times.

Figure 5
Counting the interactions

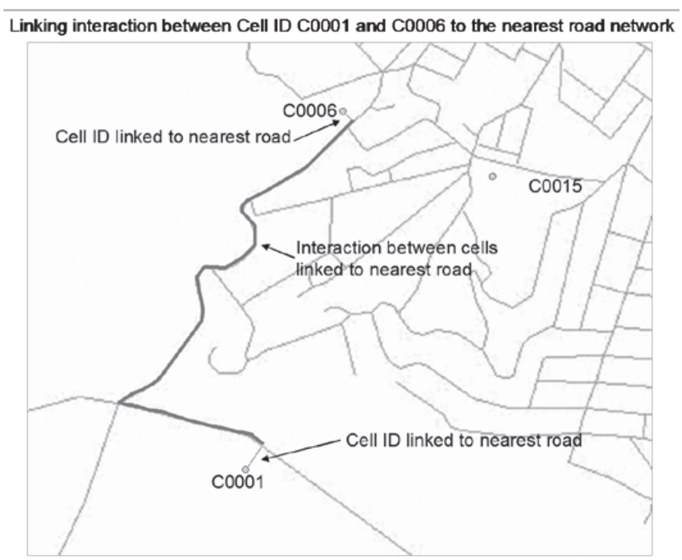


	A	B	C	D	E
1	From_Ping	To-Ping	Interaction		
2	C001	C001	1		
3	C001	C006	1		
4	C002	C002	1		
5	C002	C004	1		
6	C003	C003	2		
7	C003	C004	1		

The snapping of the interaction to the nearest road network is done using Flowmap, a software package developed by the University of Utrecht's Faculty of Geosciences. It is dedicated to analyzing and displaying flows (movement) between users (customers) travelling to facilities or services. This type of data is special in the sense that there are two different geographic locations connected to each data item: An origin location where the flow starts, and a destination location where the flow ends. The flow data itself can be people, such as commuters, shoppers, or hospital visitors; goods; and usage of agricultural services or telecommunication and so on. Most thematic mapping and GIS packages have little functionality for treating this kind of information (Flowmap, 2005).

Broadly speaking, Flowmap looks at the number of interactions between two Cell IDs, links the two Cell IDs to their respective coordinate pairs, finds the road nearest to each Cell ID location and then uses travel time to determine the nearest road network (see Figure 6).

Figure 6
Snapping the interaction to the nearest road network



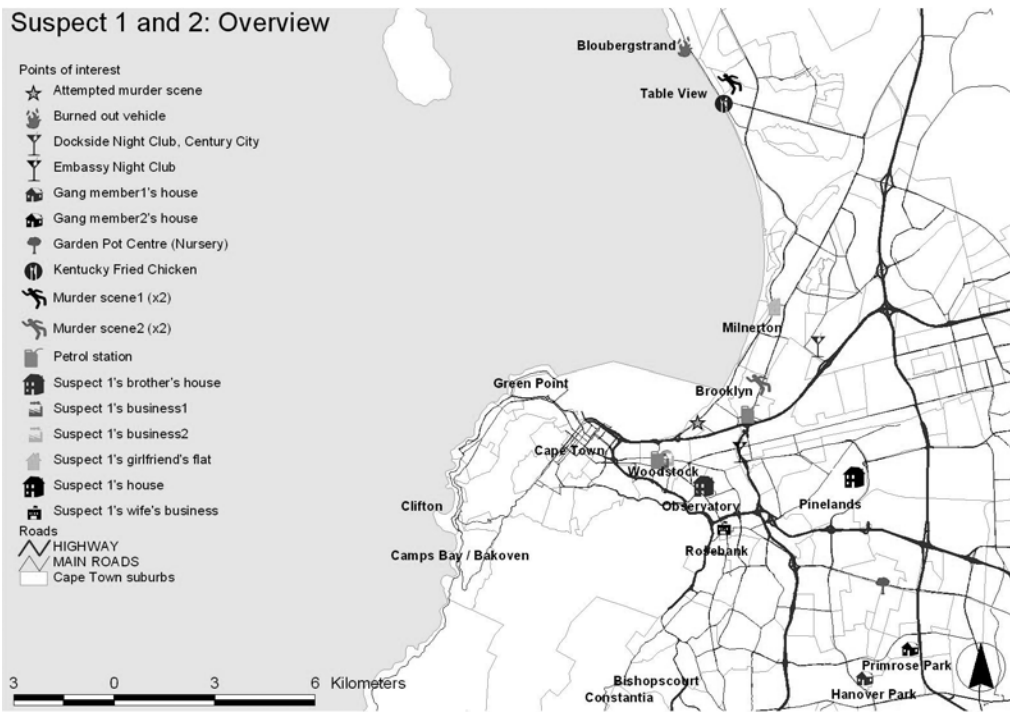
4. Examples

This article presents two examples. The first is the determination of criminal activity space using call data records, and the second is an example where the activity space is determined by using active tracking of the individual at predetermined intervals. The analysis of cellular activity can provide guidance to target investigations with the aim to bring the suspect before court.

4.1. CRIMINAL SUSPECTS IN CAPE TOWN

The call data records (CDR) was obtained from the cellular service provider using a court order by the Serious and Violent Crime Unit of the South African Police Service in the Western Cape for use in drawing maps to indicate the location of the suspect with regards to communication between the suspect and other suspects as well as in relation to where the murders were committed on two occasions for prosecution purposes. Permission was obtained from the National Prosecution Authority to use the data for the GenDySI project provided that the persons in question will not be identified. Figure 7 gives an overview of the case as well as some of the suburbs in which the points of interest to this case are located.

Figure 7
Overview of the case and study area



4.1.1. Activity space from call data records

There are two methods that can be utilised to determine the suspect's activity space. The first method is to use the cells used by the suspect and the second method is to use the suburbs as covered by the possible roads used by the suspect using the snapping to nearest road network method discussed in Section 4. Flowmap was used to snap the interaction between cells to the nearest road network. Since Flowmap has limited GIS mapping capabilities compared with the commercially off the shelf GIS software, the results were imported into ArcGIS and ArcView and mapped. Figure 8 shows the activity space of Suspect 1 (a gang leader in Cape Town) based on the latter method.

Included in the figure are the several of points of interest to case and the two murder scenes are clearly within the suspect's activity space. One of the aims of collecting cellular usage data is to establish the possible *paths* that the suspect is using to move about his activity space, this is done by snapping movement (interactions) to the nearest road network. From Figure 8 the suspect's highest road usage from his home to his businesses is determined by two routes namely direct between home and business and the second route goes past the suspect's wife's business and his brother's home. The *districts* are determined by selecting the suburbs through which the used roads traverse. Using these districts, the different *edges* can be determined by overlaying the road, rail network, rivers and selecting those features that can be a possible edge. Figure 8 shows that the main activity is occurring in the middle of the activity and the activity decreases towards the edge of the activity space.

Figure 8

The activity space of Suspect 1

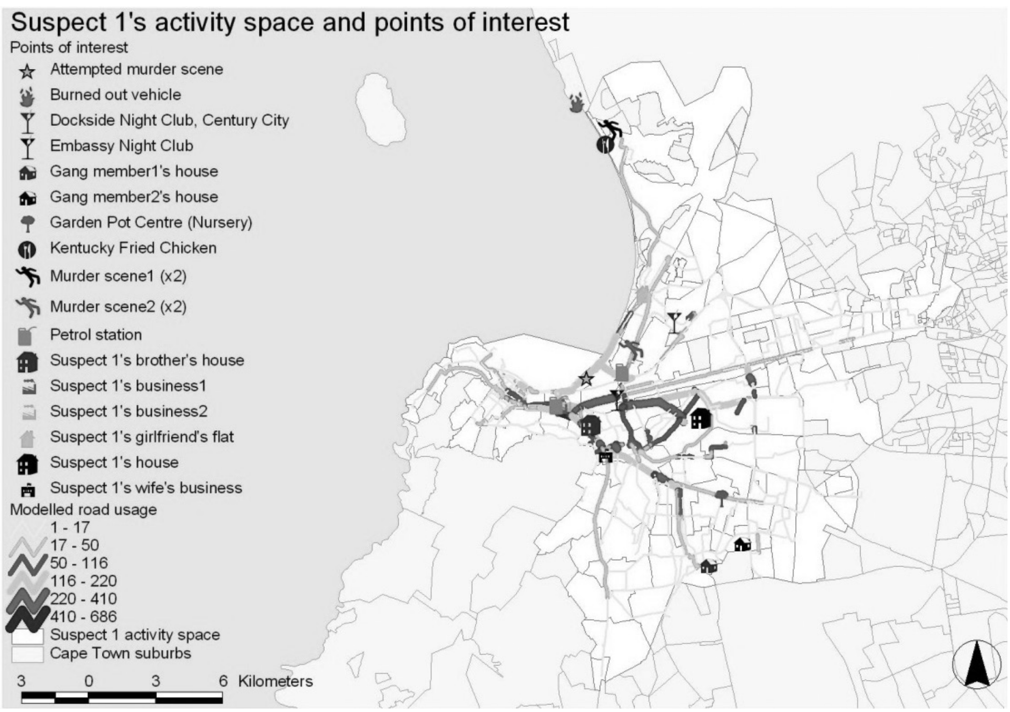


Figure 9

The activity space of Suspect 2

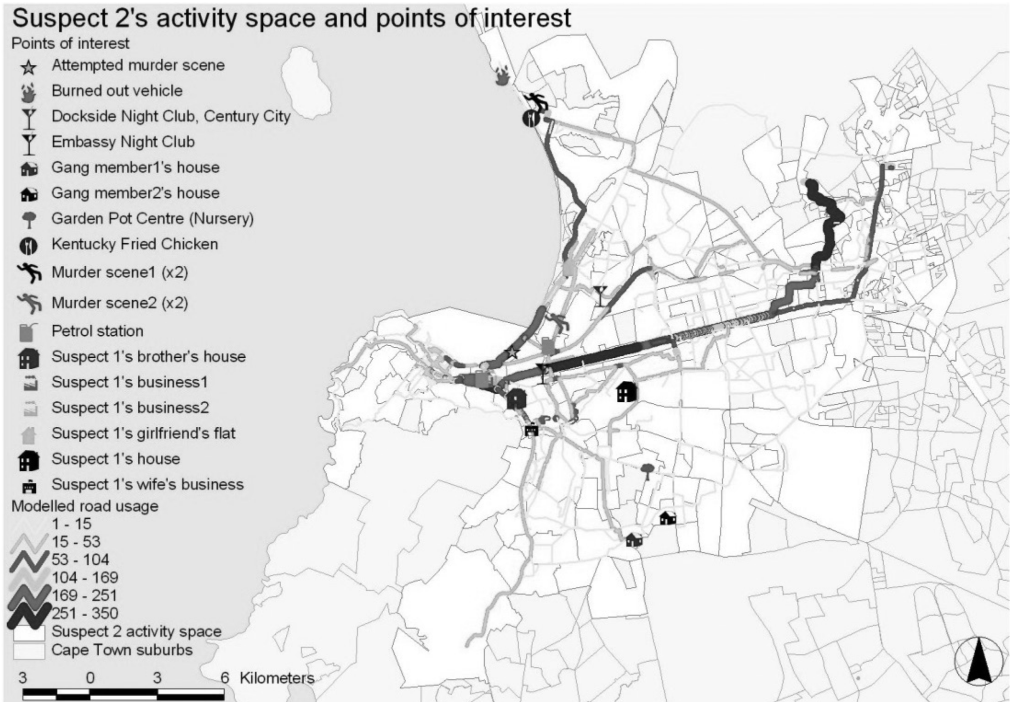


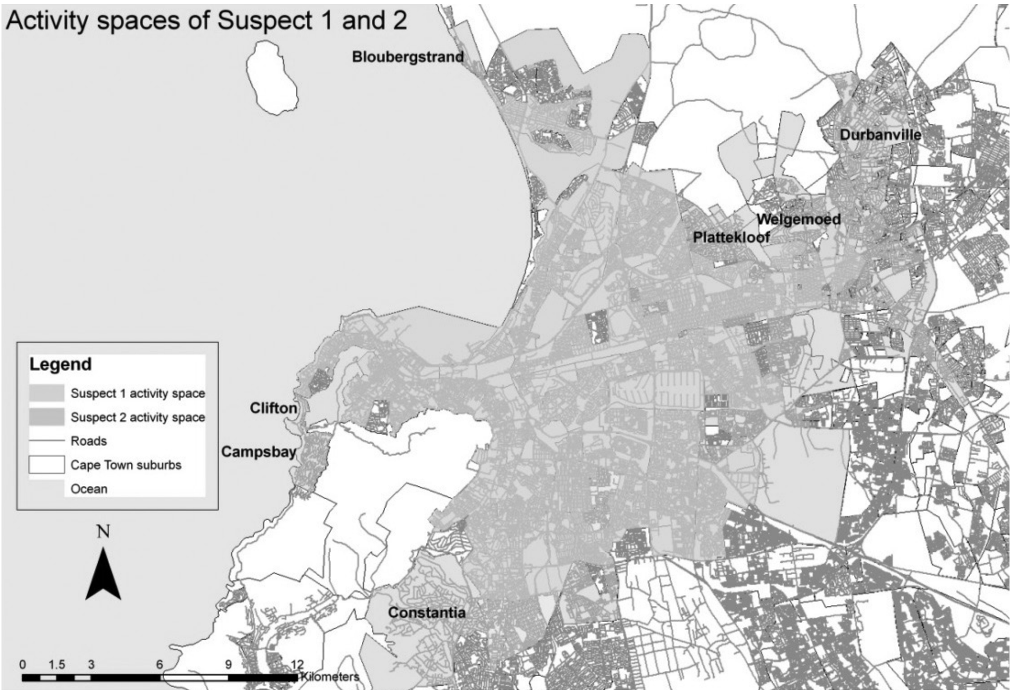
Figure 9 shows the activity space of Suspect 2, who was the gun runner or armourer of the gang. Suspect 2's activity is along a corridor starting at the northeastern part of the activity space, which is the suspect's residence along a main road (Voortrekker Rd); to west, near Cape Town, where the businesses of Suspect 1 are located. Although Suspect 2 could have used the N1, which is a freeway, to reach Suspect 1's businesses, Suspect 2's father's business is situated along Voortrekker (Dreyden, 2006). Voortrekker is also convenient for movement into the Cape Flats suburbs such as Pinelands, Mitchell's Plain and Athlone, while the N1 offers limited access to these areas.

An interesting pattern regarding the *districts* emerges as the two suspects' activity spaces are combined (Figure 10). Suspect 1 is a mixed-race person from the Cape Flats near Cape Town. Topographically, the Cape Flats is a very flat area between Table Mountain (Cape Town) and the mountains of the wine-producing areas to the east of the map shown in Figure 8 and 9. Suspect 1 lives in Pinelands, a suburb of Cape Town on the Cape Flats. Suspect 2 comes from a very wealthy white background and stayed in Welgemoed (see Figure 10). Suspect 2 fled South Africa during the investigations into the murders and has not been extradited to South Africa to stand trial (Dreyden, 2005).

The suburbs Bloubergstrand, Campsbay, Clifton, Durbanville, Plattekloof and Welgemoed area are traditionally very up-market areas of Cape Town. Due to Suspect 1's social standing and mixed race, he does not feel comfortable moving in these predominantly white, up-market areas, whereas Suspect 2's upbringing allows for easy movement in these circles. However, Suspect 2 has a substance dependency and is a weapons aficionado. To maintain his drug habit, he struck a deal with Suspect 1 to be his armourer as well as providing substance outlets in the very up-market areas where Suspect 1 could not operate. On the other hand, Suspect 2 could move easily throughout the areas which would normally have been avoided by his peers due to his relationship with Suspect 1 (Dreyden, 2005). This clearly describes the impact of the environment on the suspects.

Figure 10

Activity spaces of Suspect 1 and 2

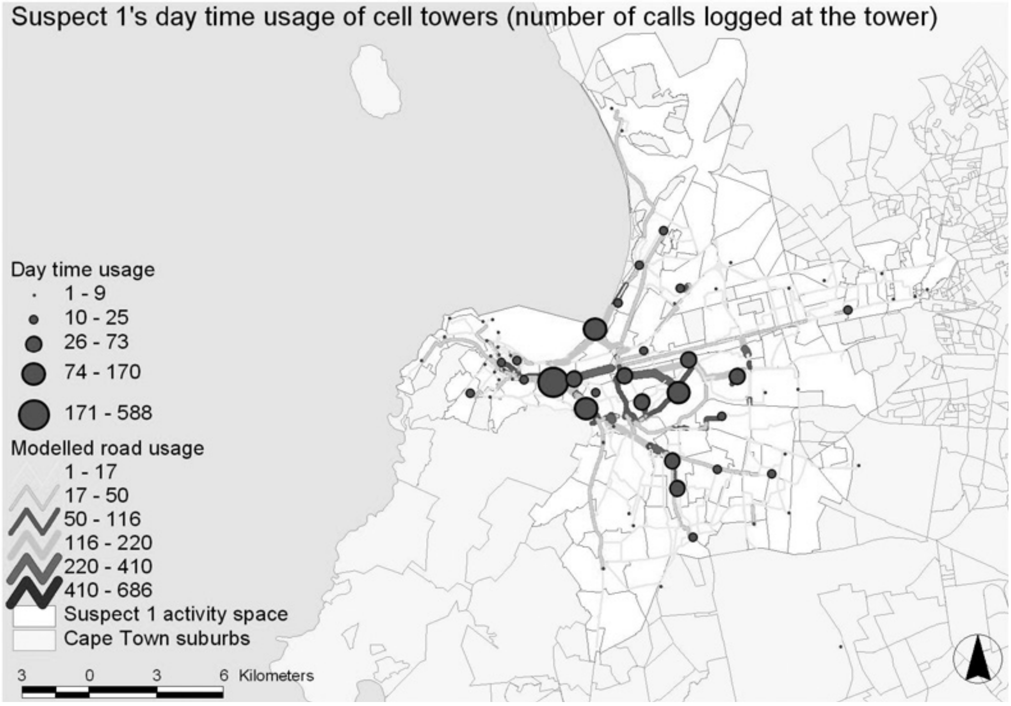


4.1.2. Diurnal pattern

The analysis of the usage of cell towers during the day and night reveals the suspect's day and night activity. Suspect 1's day activities are shown in Figure 11 and four high volume cell tower usages can be identified. Three of the four tower usages could be attributed to the closeness of anchor points to these towers, as shown in Figure 11. The fourth usage indicates an anchor point, but for demonstrative purposes there is currently no information on what this anchor point could be. Indicating the type of neighborhoods (low income, middle class, up-market or commercial) and neighborhood rhythms (areas of day or night activities) can be used to guide surveillance activities. Daytime hours were from 07:00 till 16:59 and the night-time hours were from 17:00 till 06:59. The reason for choosing 07:00 and 17:00 as breakpoints is that the datasets showed some form of a natural break with regards to cell tower usage at these times.

Figure 11

Suspect 1 day usage of cell towers



We use the same approach to establish night-time activity patterns, reviewing the data that indicates a cell tower in the vicinity of the unknown attraction where most of the night time usage occurs (Figure 12). Although night-time call volume is lower than daytime, it indicates that Suspect 1 is attracted to the area during the night. This indicates that it would be worthwhile for the investigating team to investigate and establish possible attractions such as warehouses, night clubs, and a crack house in an abandoned building. The area served by this cell tower is industrial and low income residential. The possibility exists that there could be small night clubs and adult shops in the residential area. Review of case information indicated that the suspect did frequent a nightclub in the vicinity of the cell tower (Dreyden, 2006).

Figure 12

Suspect 1 night usage of cell towers

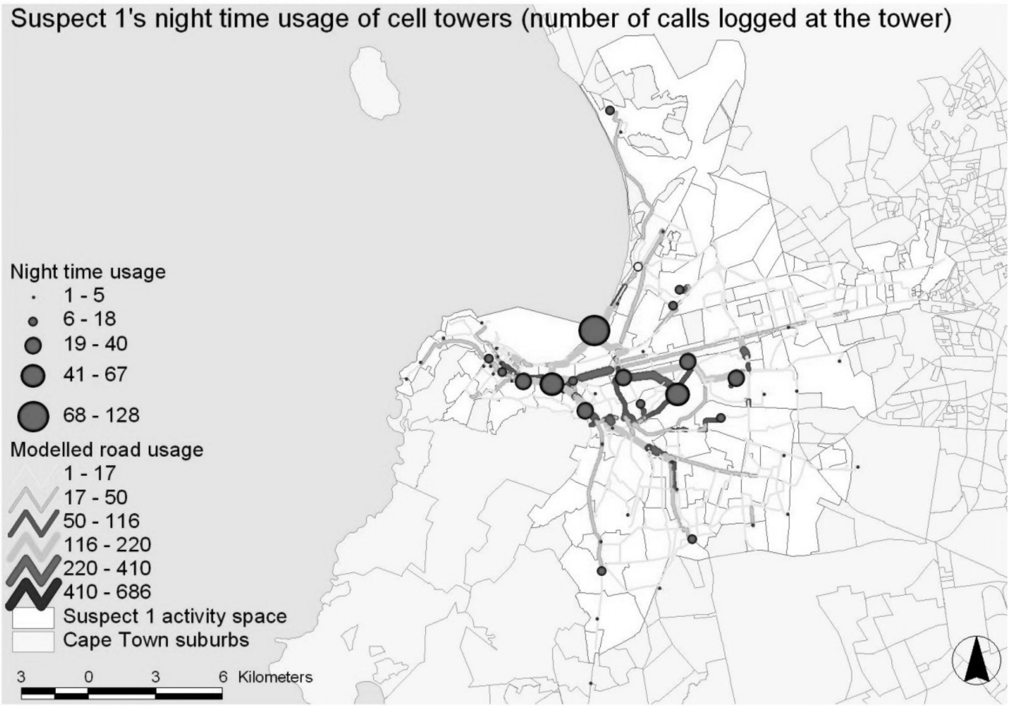
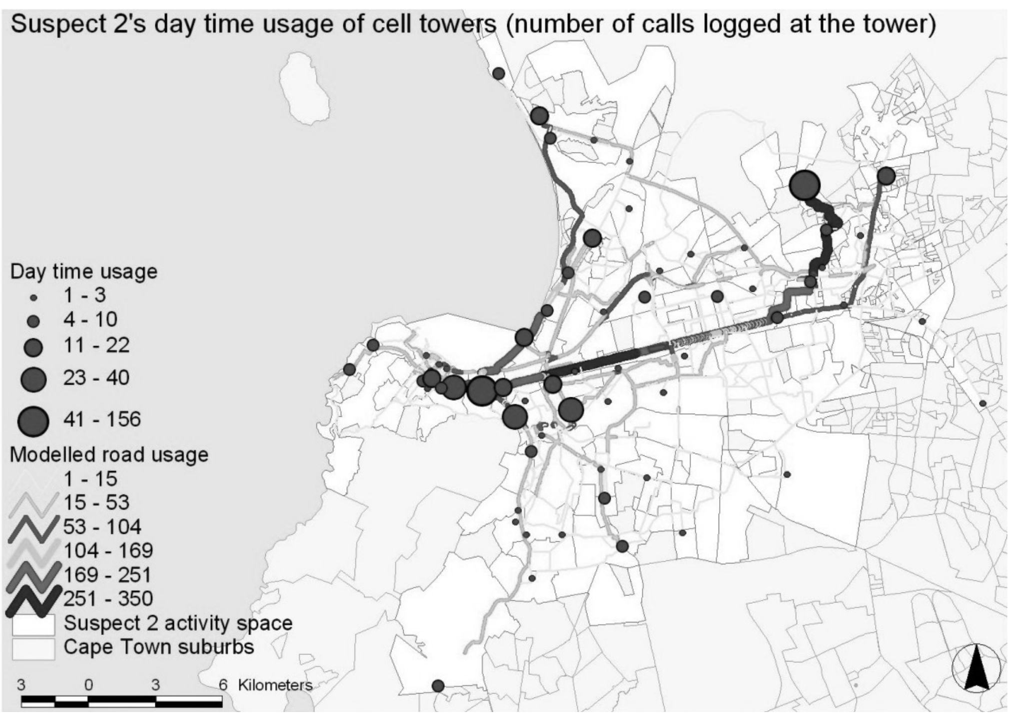


Figure 13

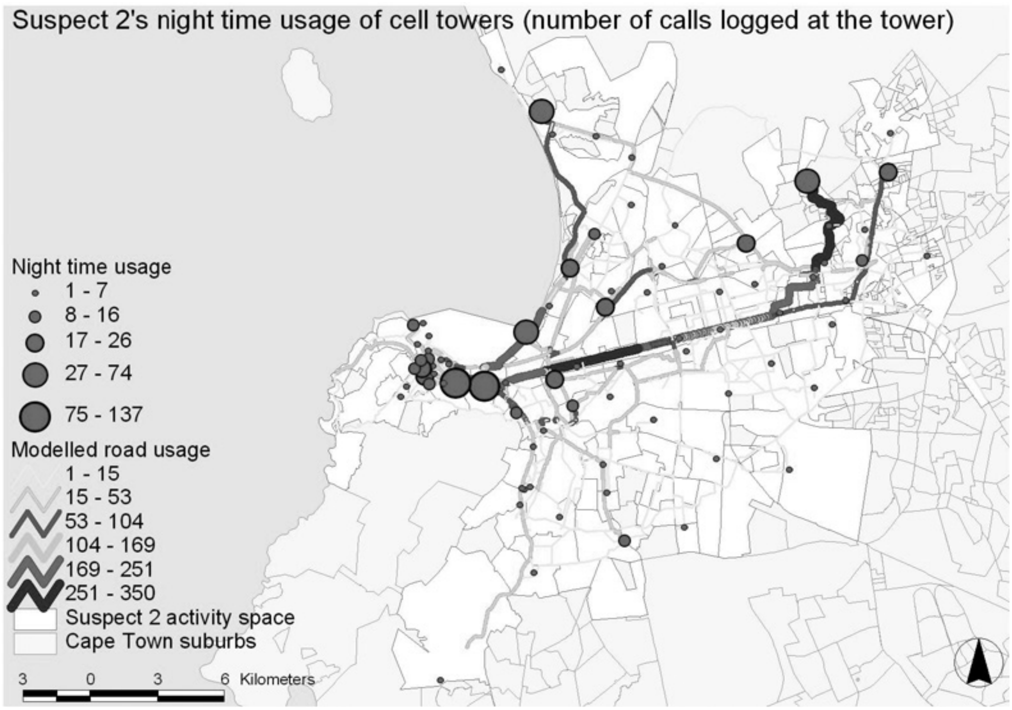
Suspect 2 day usage of cell towers



Suspect 2's usage of cell towers during the day is mapped in Figure 13 and clearly shows the connection between Suspect 1 and 2. Two distinct nodes are identified, namely around Suspect 2's home location and around the business of Suspect 1, along with increased usage near those locations, similar to Suspect 1 activity. However Suspect 2 shows a much livelier night-time activity than Suspect 1, especially in downtown areas of Cape Town and north of the activity area of Suspect 2. Both Suspect 1 and 2 were near the tower located near a night club (Figure 14). Two of the murder victims were linked to that night club (Dreyden, 2006), shown as Murder Scene 2 in Figure 8 and 9.

Figure 14

Suspect 2 night usage of cell towers



4.1.3. Frequency of calls indicating anchor points

The previous section briefly discussed the day and night usage of cell towers by Suspect 1 and 2 as well as the possible conclusions made that can assist in directing investigations. This section looks at the combined number of usages of the different cell towers used by Suspect 1, which is then used to determine the cell towers that are used most frequently, irrespective of day or night. Figure 15 shows the frequency of use of all the towers that Suspect 1 used in relation to points of interest (POI) to the investigation. The investigation team can then select a number of towers that can indicate the presence of *nodes* (see Section 2) due to the high usage of these towers or cells. In this study with regards to Suspect 1 eight *nodes* have been identified (Figure 16). The usage is broken down in one-hour time slots to determine the temporal rhythm of the suspect.

Figure 15
Cell tower usage by Suspect 1

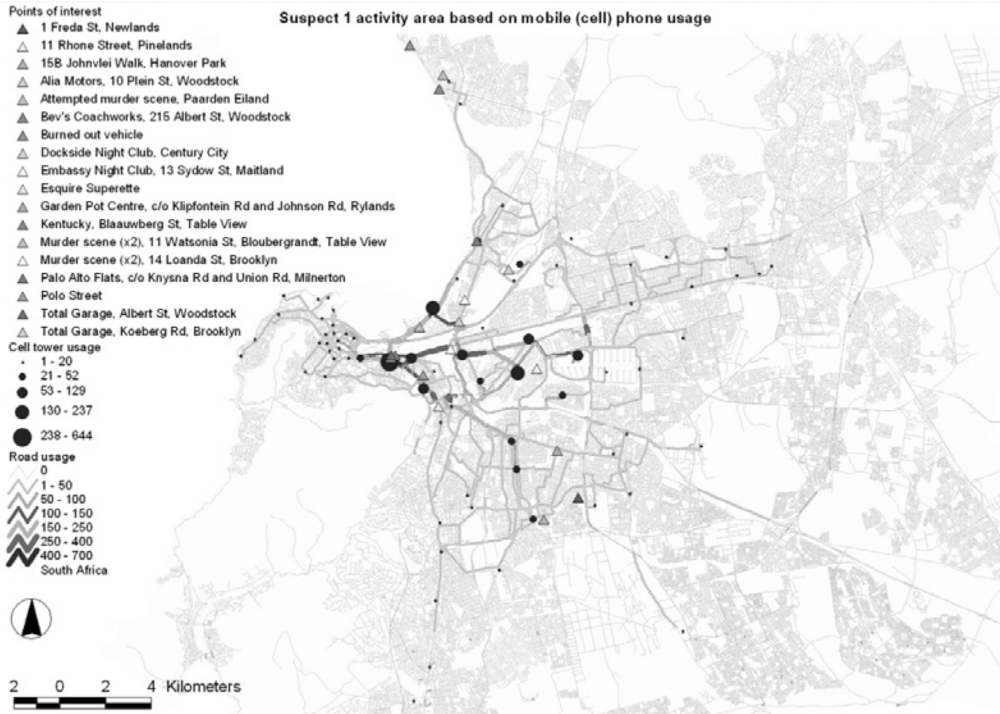


Figure 16
Suspect 1's top eight most frequently used cell towers

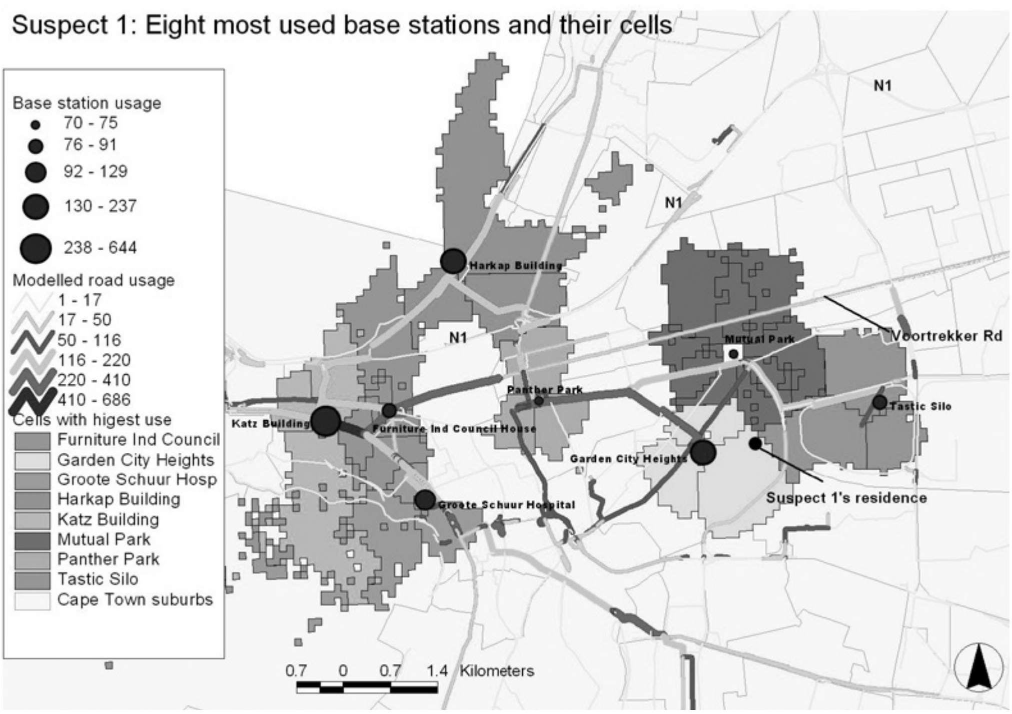
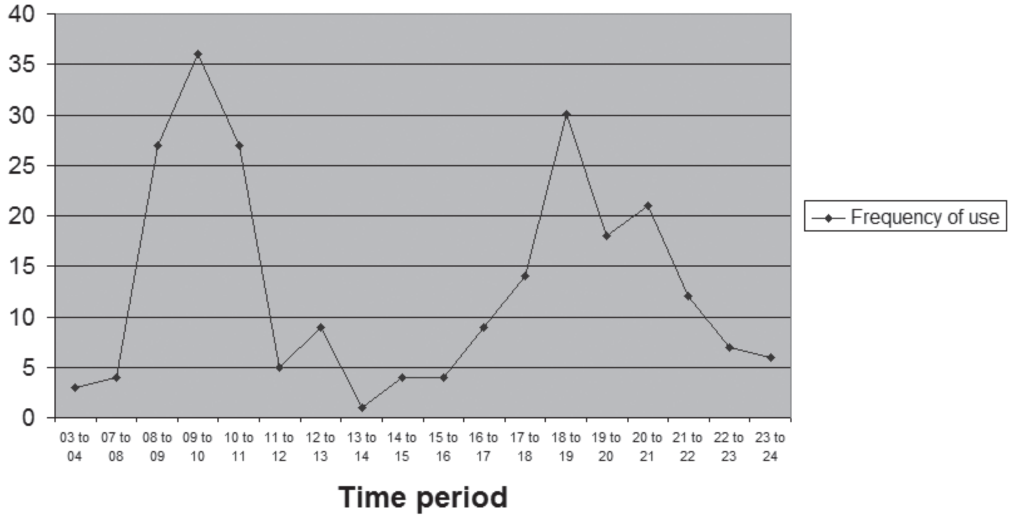


Figure 17

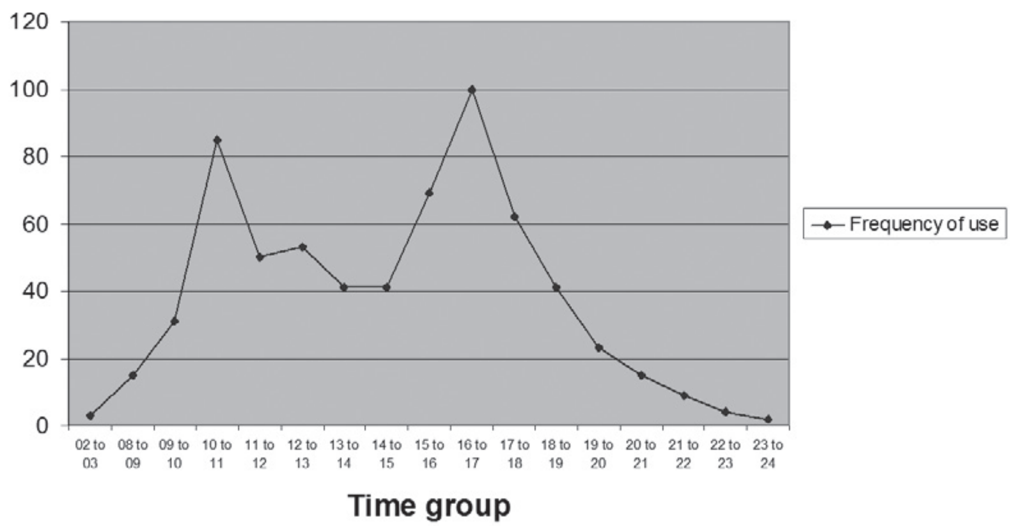
Usage of the Garden City Heights base station



This graph (Figure 17) shows the base station (cell tower) usage that covers Suspect 1's home. It shows a normal "at home" cellular telephone usage, namely morning usage and evening at home usage, tapering off towards midnight. Figure 18 gives the usage of the Katz Building base station which is the base station that covers Suspect 1's two businesses.

Figure 18

Usage of the Katz Building base station



This base station has a much higher frequency of use when compared to the base station that covers Suspect 1's home. Activity occurs over normal business hours between 9 to 5. However, there is a decline in usage during lunch hour between 1 and 3 o'clock in the afternoon. The lower frequency of use at the Katz Building base station is explained in Figure 19 and 20.

Figure 19

Usage of the Panther Park base station

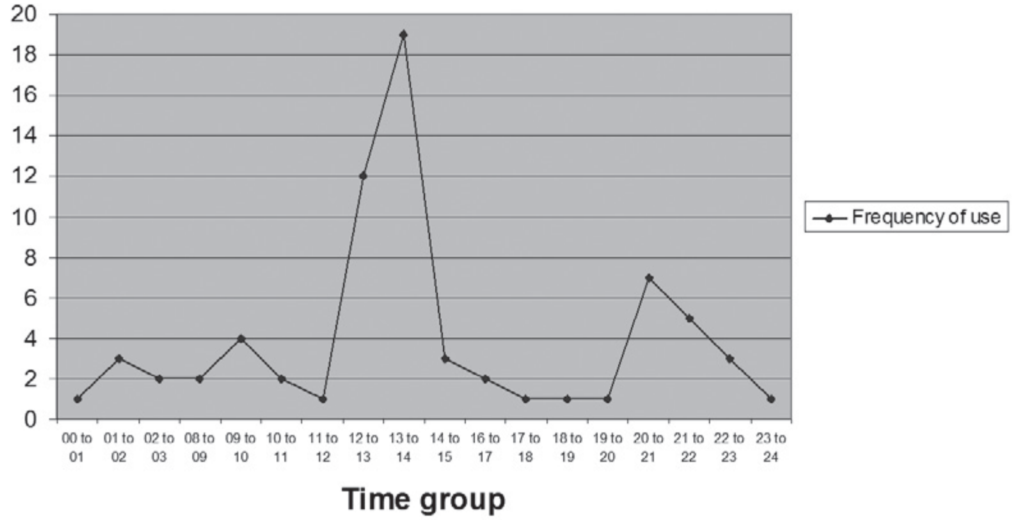
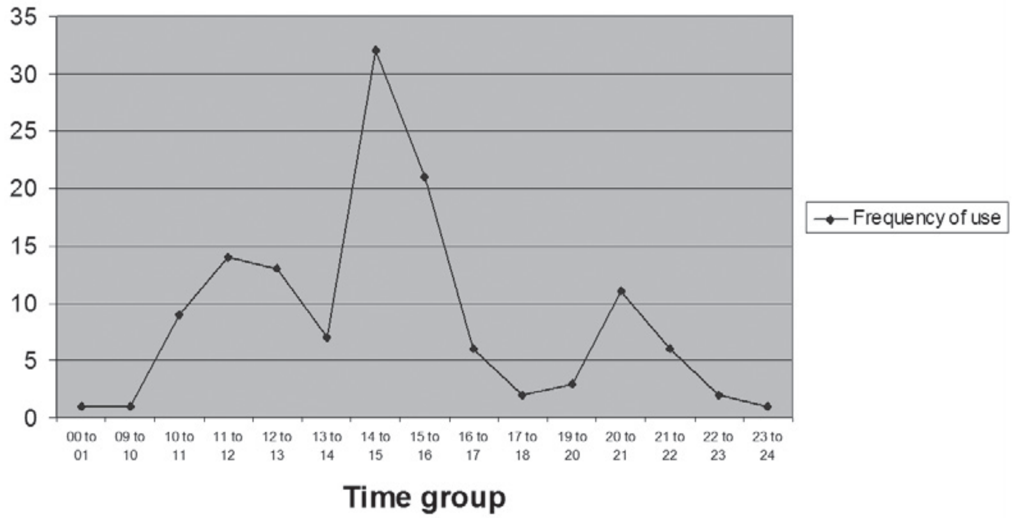


Figure 20

Usage of the Groote Schuur Hospital base station



The lunch hour peak usage is clearly visible in Figures 19 and 20. Within the coverage area of the Panther Park base station (Figure 19), Suspect 1 visits a Nigerian drug lord who provides drugs to Suspect 1, who then distributes the merchandise amongst his pushers to sell it to their "clients" (Dreyden, 2006). The residence of Suspect 1's brother and the business of Suspect 1's wife are both served by the Groote Schuur Hospital base station, and indicates that he could have paid occasional visits during lunch hour to his brother and wife (Figure 20).

Figure 21
Usage of the Harkap Building base station

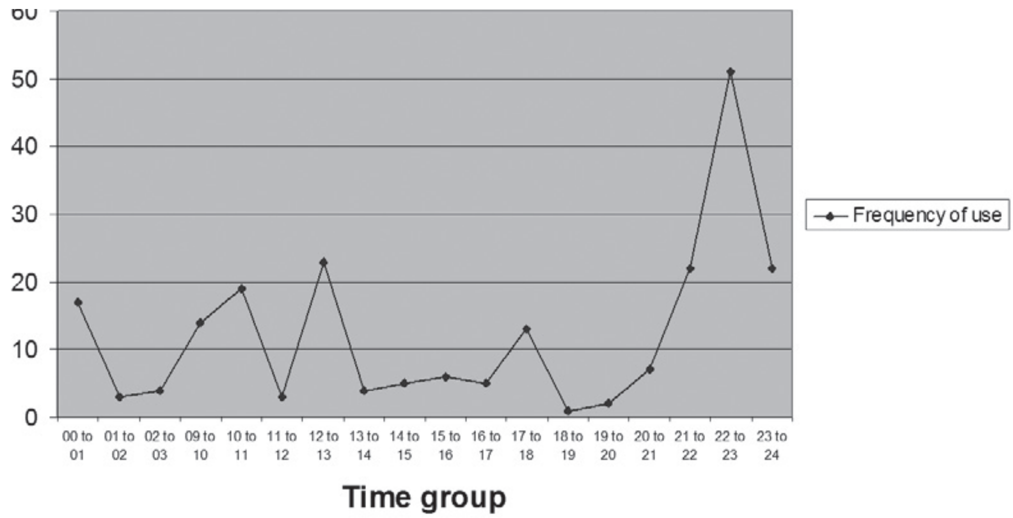


Figure 21 shows the base tower with the second highest usage. This is the base station that indicated the unknown attraction in Figure 8 and 9, which was later identified as a night club (Dreyden, 2006). It clearly shows the patronage of the night club which Suspect 1 left between 2 and 3 o'clock in the morning. As previously mentioned, two of the murder victims were connected to this night club (see Figure 7, Murder Scene 1 at Brooklyn). They were rival gang members who were also connected to the two murder victims found at Murder Scene 2 at Table View (Figure 7) (Dreyden, 2005).

Figure 22
Usage of the Mutual Park base station

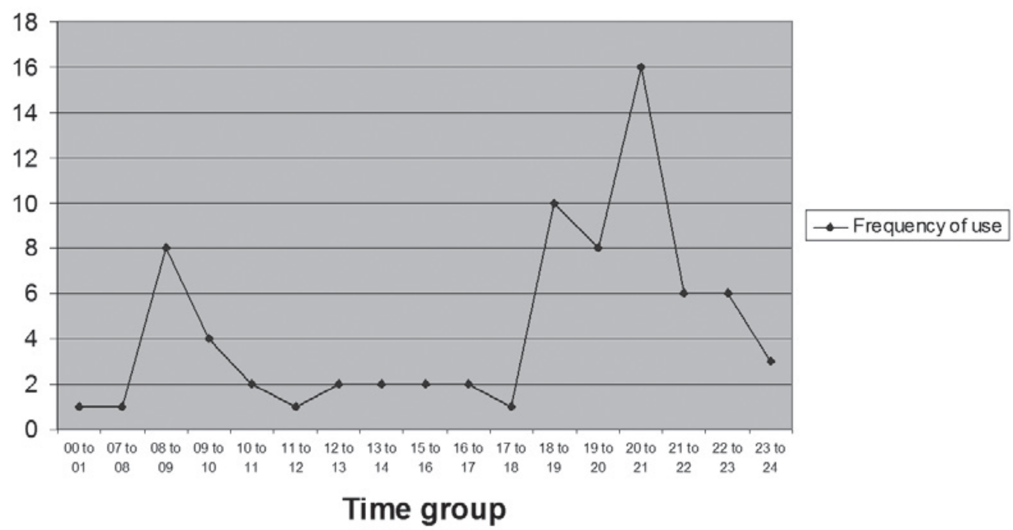
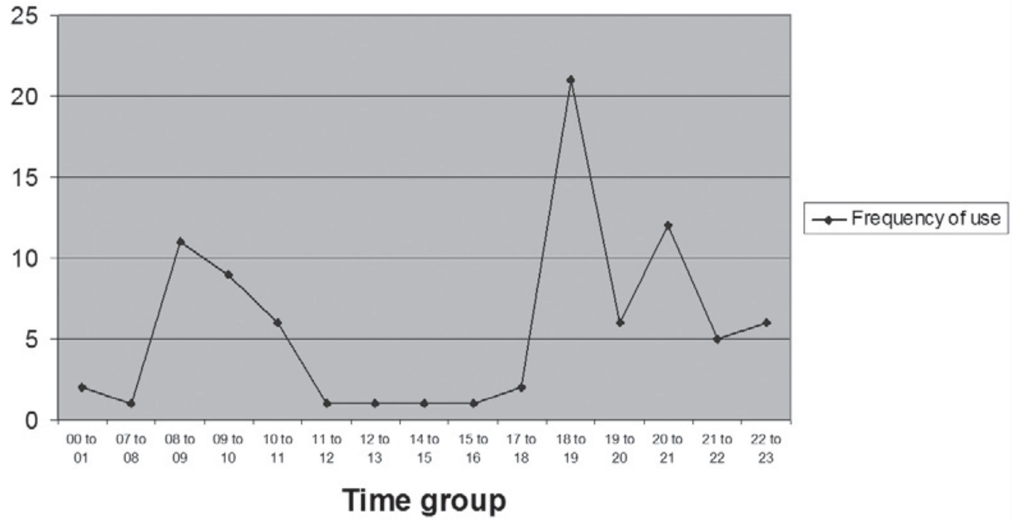


Figure 23

Usage of the Tastic Silo base station



The areas covered by the Mutual Park and Tastic Silo are close to Suspect 1's residence, which is covered by Garden City Heights (Figure 16). Since both graphs indicate similar usage than the graph of Garden City Heights (Figure 17) the assumption can be made that these base stations were used when Suspect 1 was driving through them, leaving home or returning. Suspect 1 needs to drive through the coverage of the two base stations when accessing Voortrekker Rd or the N1 (Figure 16).

Figure 24

Usage of the Furniture Industry Council House base station

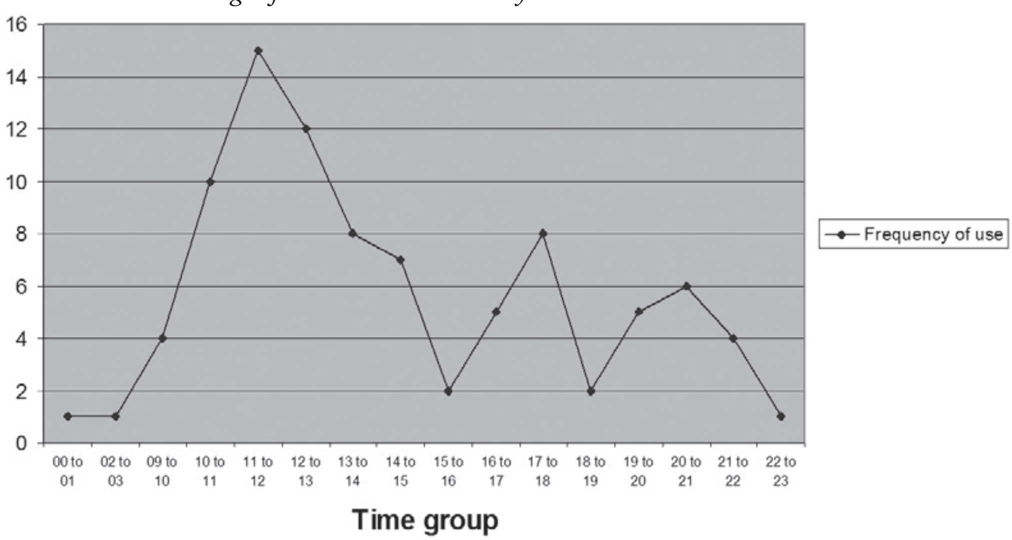


Figure 24 shows the usage of the Furniture Industry Council House base station. Owing to location of the cells of the base station, which are next to the cells covering the businesses of Suspect 1 (Katz Building), the assumption can be made that Suspect 1 is driving through the coverage area. His travel may be leaving or arriving at the businesses; to and from his brother's residence or his wife's business. The Nigerian drug lord and the nightclub also fall within the coverage of Harkap Building base station (Figure 16).

The above few sections discussed the analysis and possible deductions that can be made using call data records (CDR) over a specified time period. The next section will discuss the analysis and deductions that can be made when an individual is being actively tracked (pinged) at intervals over a specified time period.

4.2. TRACKED INDIVIDUAL IN PRETORIA

The second methodology to determine a criminal suspect's activity space is by actively tracking the suspect by pinging the suspect's cellular telephone at a specified time interval, discussed in Section 3.2. For this study the project team used a volunteer from a forerunner to this study (see Krygsman and Schmitz, 2005) to analyse the individual's data for the purpose of establishing activity space and possible anchor points. The data of the volunteer used for this analysis was collected as part of the previous study, which looked at the concept of tracking individuals to determine the travel behavior, with the aim to provide data for transport modelling and management (Krygsman and Schmitz, 2005). For the purpose of this discussion the individual will be called *Individual 1.*

4.2.1. Active tracking

Section 3.2 discussed the methodology employed to track an individual by pinging the cellular telephone at a regular interval over a specified time period. *Individual 1*'s cellular telephone was pinged every five minutes over a 48-hour period, starting at 6 o'clock in the morning and ending at 6 o'clock 48 hours later. This resulted in 577 pings, each with a date-time stamp and latitude and longitude location. The next section briefly discusses the activity space of *Individual 1.*

4.2.2. Activity space and anchor points

In Section 5.1.1 the activity space was determined using the roads that were used by the Suspect 1 and 2 to select the suburbs which they traverse. Figure 25 shows the activity space of *Individual 1* using the same method. The eastern and central suburbs of Pretoria form the person's activity space. Pretoria Central, Brummeria and Constantia Park can be identified as the main anchor point suburbs using the number of pings per cell (cell use). Pretoria Central is the downtown area of Pretoria, consisting of private enterprises such as retail, services, and government offices. Brummeria is residential and research (CSIR) and Constantia Park is residential. Shopping malls are located in the suburbs of Lynwood Manor and Menlyn, which act as attractors. Based on review of land use, the assumption can be made that the person's residential anchor point is in Constantia Park. In Brummeria, it is difficult to decide whether the research institute (CSIR) or the residential area (second house or the home of a friend or relative) acts as an anchor point. This can be clarified through targeted intelligence gathering by an investigator, determining the attractiveness of the downtown area in terms of night clubs, hotels, adult shops, and similar establishments. Figure 26 shows the activity space using cell coverage.

Figure 25

Activity space using suburbs

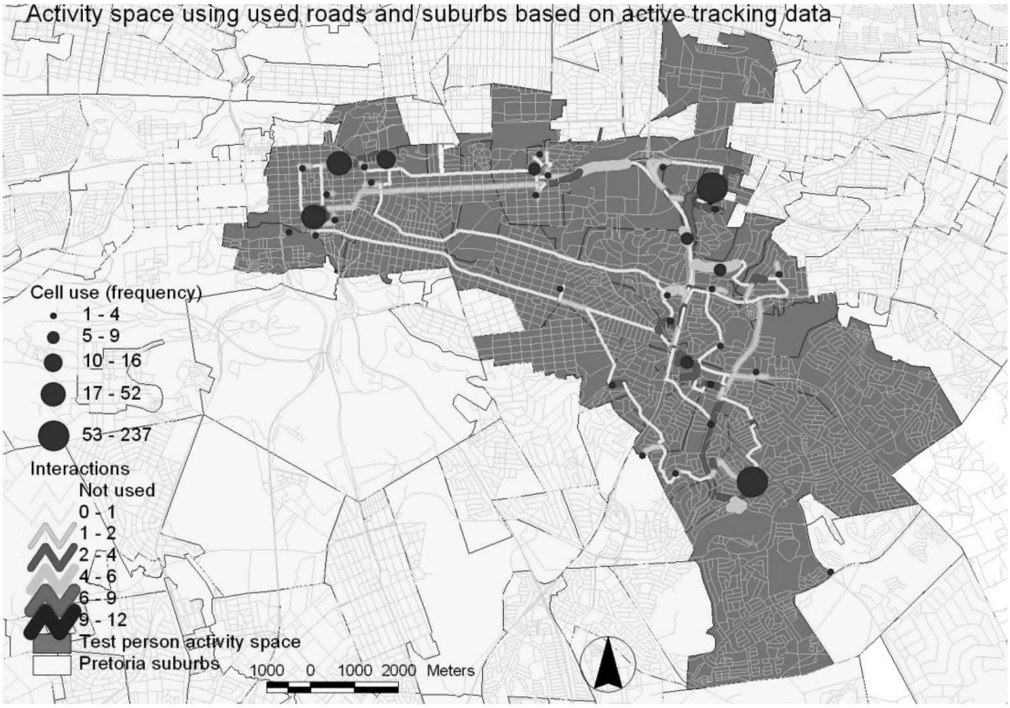
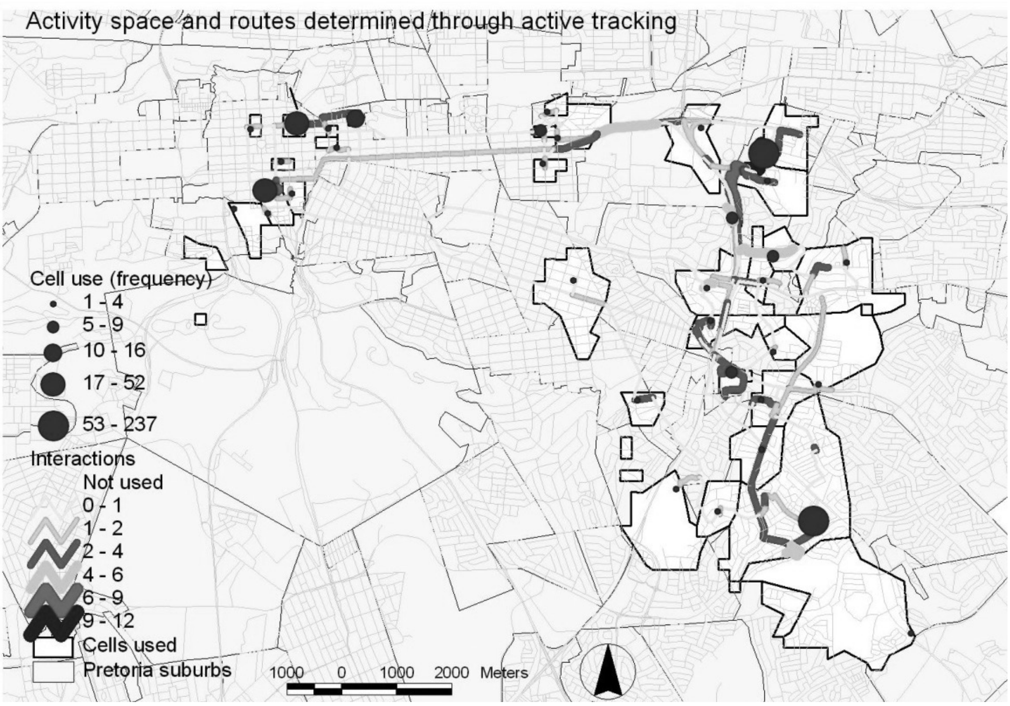


Figure 26

Activity space using cell coverage



When using the cell coverage as a starting point to determine the activity space of a suspect, the underlying suburbs and/or land use needs to be determined to establish possible attractions. The anchor points provided by *Individual 1* are:

- Constantia Park – residence
- Brummeria – workplace (CSIR)
- Pretoria Central – two government departments that contracted the person to do research for them
- Lynnwood Manor and Menlyn – shopping malls frequented by the person
- Hatfield – car dealership visited by the person during the tracking exercise.

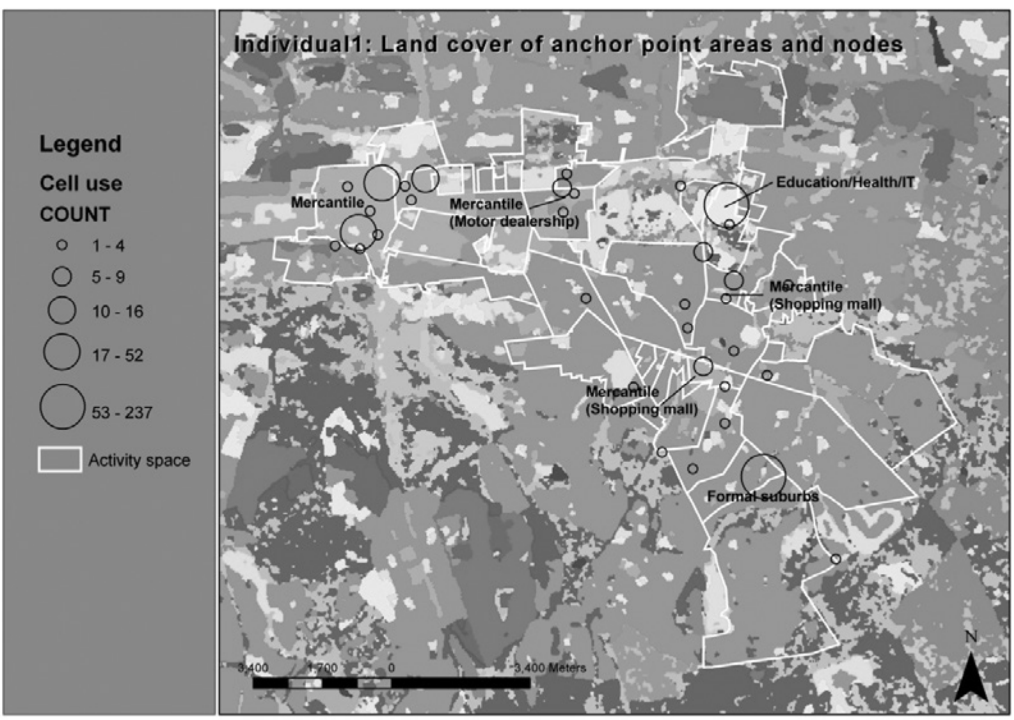
Figure 25 and 26 clearly shows *Individual 1*'s possible paths to travel between the three anchor points (residence, work and downtown Pretoria). The following districts can be identified using additional information, such as land use or land cover. The following land cover has been identified at the three anchor points (Figure 27):

- Mercantile (downtown Pretoria)
- Education/Health/IT (work)
- Formal suburbs (residence)

The nodes consist of two shopping malls and a motor car dealership (Figure 27). The shopping malls and the motor vehicle dealership cannot be inferred from the land cover map, but the land cover map can give an indication what to look for. These finer details can only be collected using local knowledge and targeted intelligence gathering. The next section looks at the diurnal pattern of the tracked individual.

Figure 27

Land cover classes and the activity space of Individual 1



4.2.3. Diurnal pattern

07:00 through 16:59 were denoted as day-time activities, and night-time hours from 17:00 until 06:59. Apart from the natural break noted in the dataset, it is also the normal workday and commuting hours in South Africa. Figure 28 shows the day-time usage of the cells by *Individual 1* which clearly indicates the two daytime anchor points; namely his workplace and the two government departments for which he does some contract work. Figure 29 shows his night-time anchor points, namely work and home. Both figures show only the cells use but does not indicate which part of the day or night the individual uses these cells. It is similar to the Cape Town example where the call data records (CDR) showed when calls were made or received and at which tower (Section 5.1.3). Here it is determined when the first ping and last ping were received in a particular cell. These are shown in Figures 30 and 31. In Figure 30 (day-time track) *Individual 1*'s tracking data indicated that the first ping in the two most-used cells in Pretoria Central was received between 8 and 9 o'clock and 10 and 11 o'clock in the morning respectively; and the last ping between 4 and 5 o'clock in the afternoon. The first ping was also observed between 8 and 9 o'clock in the morning at *Individual 1*'s work place (Brummeria) and the last ping between 2 and 3 o'clock in the afternoon. This can indicate that the person moved during the day between these two anchor points, showing a high potential for mobility during working hours.

Figure 28

Individual 1*'s day time activity pattern*

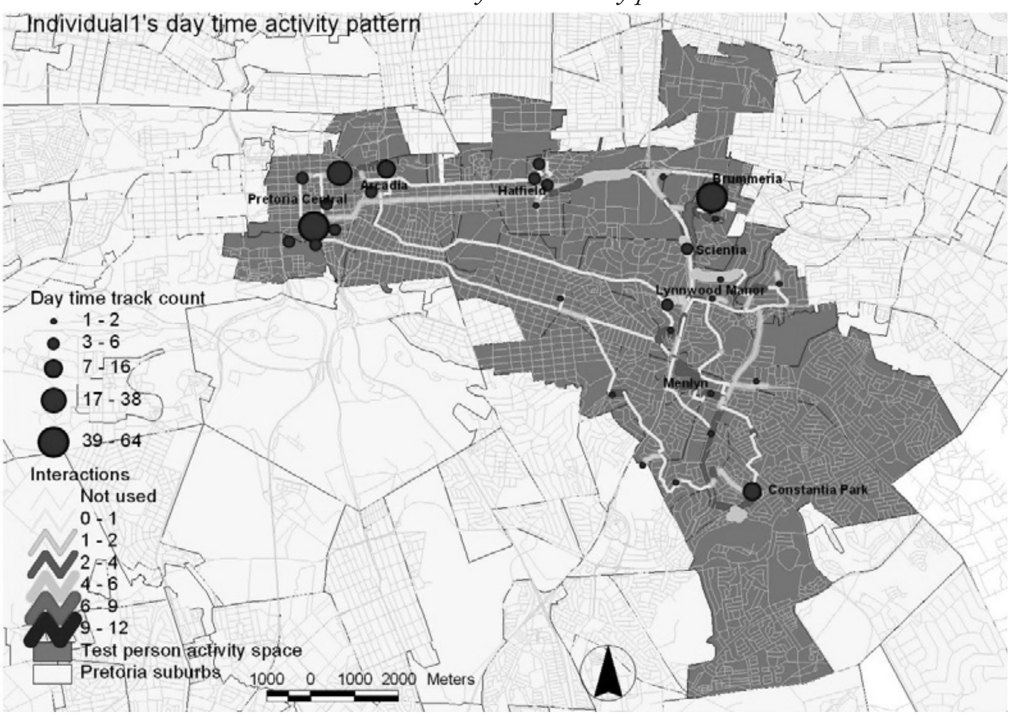


Figure 29

Individual 1*'s night-time activity pattern*

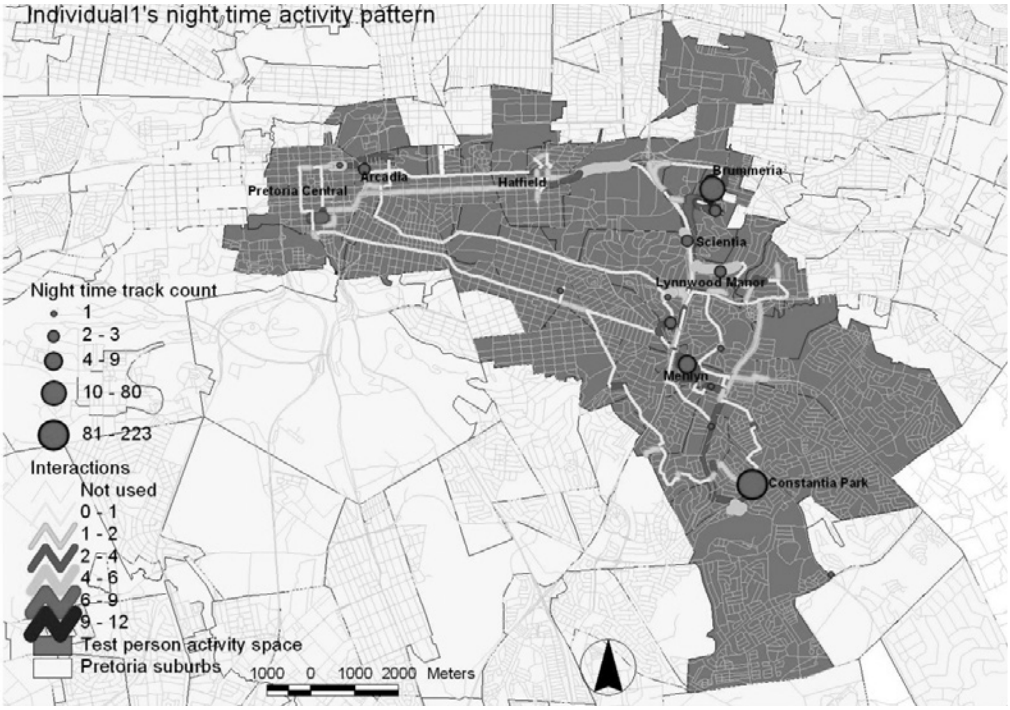


Figure 30

Individual 1*'s first and last use of selected cells during the day*

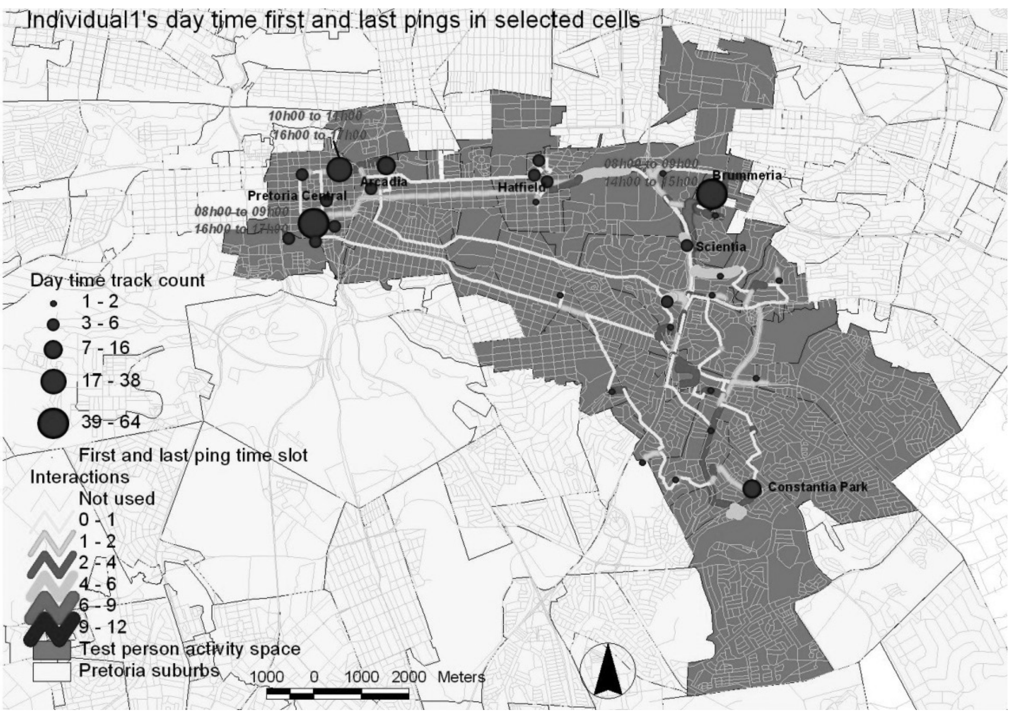
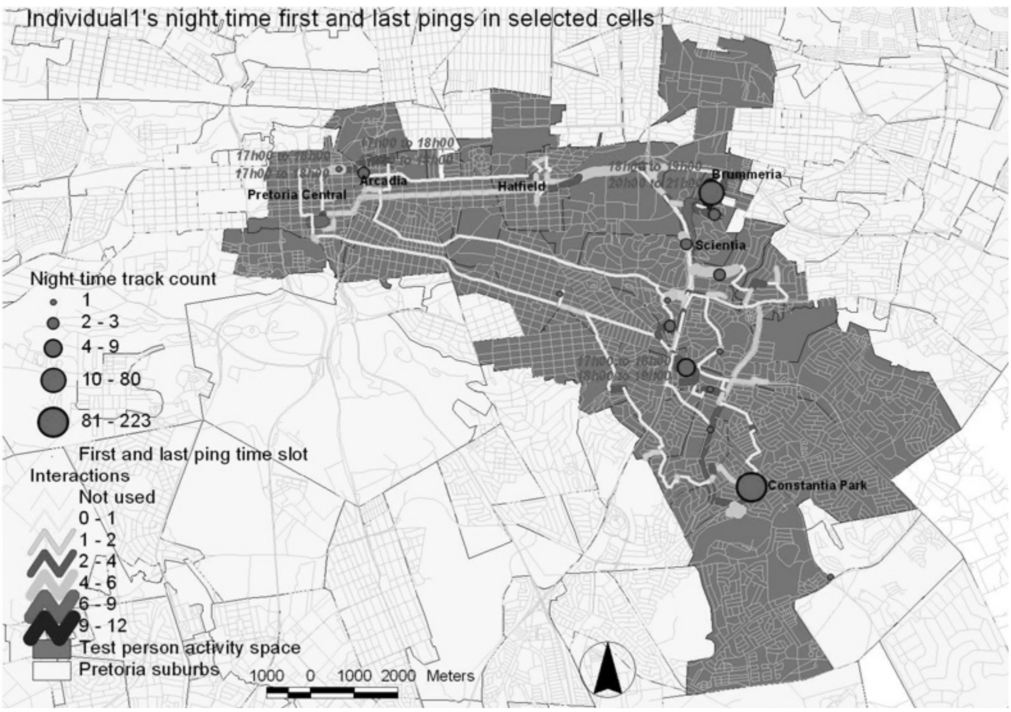


Figure 31 shows the first and last pings for selected cells during the night-time activity of *Individual 1*. The first and last pings for the two selected cells in Pretoria Central show that the person moved away from that area between 5 and 6 o'clock in the early evening. The person could have either gone to the shopping mall or to his place of work (Brummeria). The reason that the cell of his residence (Constantia Park) does not show any first and last pings is that using an automated process to determine the first and last ping does not make any sense, since the first ping was between 5 and 6 o'clock in the morning and the last one was between 6 and 7 o'clock in the morning, which is one hour; and the total number of pings is 237 at that cell. A different approach is needed to establish the pattern with regards to time at the cell that covers *Individual 1*'s residence. A manual process establishes that *Individual 1* returned home between 9 and 10 o'clock in the evening and left at the latest between 7 and 8 o'clock in the morning. *Individual 1* returned and left home during the day between 2 and 3 o'clock in the afternoon. The above analysis was done over a 48 hour period. Finer analysis of movement can be made by splitting the data into 24-hour periods.

Figure 31

Individual 1*'s first and last use of selected cells during the night*



5. Conclusion

Using call data records (CDR) and/or active tracking data it is possible to determine the activity space of an individual using cellular telephone data. The data alone is not sufficient and needs to be supported by local knowledge and gathered intelligence. Dreyden (2006) indicated that analysis done using CDR and/or results from active tracking of the handset of a suspect will drastically improve targeted intelligence-gathering activities. This analysis offers the investigating team an effective method to brief new officers joining the investigation with regards to the suspect's activity space, anchor points and the suspect's day/night activity. These analyses, along with the results of the CDR analysis, can guide active tracking. Dreyden (2006) mentioned that the active tracking of a suspect can help the investigators establish finer detail on specific movements than what CDRs alone can provide. It is strongly recommended that the above should not be used for prosecution purposes, but only to provide assistance with solving a criminal case.

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