Chapter 6
Reconstitution of the Journeys to Crime and Location of Their Origin in the Context of a Crime Series. A Raster Solution for a Real Case Study

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Abstract In the region of Charleroi (Belgium), a series of criminal acts were committed by the same group, using the same vehicle. The events were located in space and time. The car used during these criminal activities was stolen (first event) and was later retrieved (last event) after a period of 4 days of offences. Police recorded a crucial clue: the total mileage covered by the vehicle between the first and the last event was estimated with an admissible approximation. Thanks to this information, we were able to choose the most probable journey-to-crime among several scenarios. These depended on the combination of cost surfaces built with distance propagation algorithms starting from each criminal event in raster mode. The distance propagations were limited to the road network and the combinations of the cost surfaces had to respect the chronology of the facts. The most plausible scenario suggested that the criminals hided the car into a withdrawal site between their activities. In order to improve the precision of the location of this withdrawal site, we used a multi-criteria analysis taking account of the journey of the vehicle and other environment variables. At the end of these treatments, the small stretch of road that we isolated actually included the withdrawal site, as confirmed by the police later.

Keywords Geographic profiling • Road network • Cost surfaces modelling • Multi-criteria analysis • Withdrawal area delineation

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6.1 Introduction

6.1.1 Generalities

Journey-to-crime (JTC) has significantly increased and broadened its scope over recent decades. The scientific researches are led by many diverse disciplines such as criminology, geography or psychology with as many different concerns. While some of them study the behavioural or socio-economic offender's characteristics influencing the traveled distances (Lundrigan and Czarnomski 2006; Lundrigan et al. 2010; Snook et al. 2005), others, like geographers, develop new techniques, governed by spatial principles, in order to delineate prior search areas for the offender. It is what Rossmo (2000) defined as geographic profiling and several software packages, such as CrimeStat (Levine 2007), Rigel (Rossmo 2000), Dragnet (Canter et al. 2000), have been developed to automatically delimit this search area.

This book chapter proposes a new methodology structured around three original aspects for geographic profiling: the environmental influence on the choice of crime sites, a raster-based methodology and an operational-oriented solution.

6.1.2 Environmental Influence

Environmental criminology demonstrated the influence of the environment on criminal behaviours (Brantingham and Brantingham 1981). Somes studies considered environmental factors in geographic profiling (Kent and Leitner 2009; Snook et al. 2005; Mohler and Short 2012).

> Operationally the crux of geographic profiling involves combining geographical theory and research with our experience of offender behaviour, while considering relative environmental factors and forensic issues,… (Daniell 2008).

The influence of the environment interfering with the shape of the distance decay function is widely recognised. The new Bayesian approaches introduce matrix of origin–destination in order to integrate the influence of several, combined, unknown features on the chosen journeys (Levine and Lee 2009; Kent and Leitner 2009; Leitner and Kent 2009).

Many aspects of the environment could nevertheless be directly integrated into the modelling of JTC. First of all, the road network poses constraints to the offender's movements and directions. It is often admitted that Euclidean or Manhattan distances provide accurate geoprofiles (Kent et al. 2006; Canter 2003). However, Alston (1994) mentions that micro-spatial behaviours for sexual rapists in England were completely different from those in North-American cities because the organisation of cities influence the offender's mobility. By contrast to the North-American cities that present a quite regular grid organisation, European cities have been modelled by successive, often uncontrolled developments making their structure very complex. Their irregular networks challenge the classical use of direct and indirect distances. "Besides, transportation modellers usually conceptualize distance not as an independent variable but as the result of predisposition, attraction and networks" (Levine and Block 2011).

Identifying all the physical or social barriers of the JTC is impossible (Bernasco and Block 2009). Some rough aspects like the exclusion of uninhabited areas (water bodies, woodlands, *etc.*) or of specific route categories, avoided because of police monitoring, could nonetheless restrict the search area.

6.1.3 Crime Mapping Research and Raster Analysis

Geospatial analysis can be done in two ways, depending on how the spatial primitives are defined and structured. The point defined in 2 or 3 dimensions is the geometric primitive of the vector mode. It allows the use of spatial entities such as segments, poly-lines, polygons and volumes. The raster mode considers a grid of cells covering the territory. Its geometric primitive, the cell, has a surface which introduces a bias in the analysis of linear or point features. However, the contiguity of grid cells allows treating spatially continuous phenomena. Indeed, in raster mode, the thematic dimension is given by the numeric values of the grid while its spatial dimension is computed thanks to the relative position of the cell in the grid. This format allows computing quick treatments on large amounts of data like those describing continuous phenomena.

In crime analysis, the vector approach has been preferred to the raster approach. Centrographic statistics, such as centroids and ellipses of dispersion (well described in Chainey and Ratcliffe (2005)) and applications of graph theory such as searching the shortest path (e.g. Qian et al. 2011), all emerge from the vector mode.

However, the ability to process spatial continuity offered by the raster mode allows the integration of environmental phenomena in the analysis. In addition, the matrix structure of information in raster mode allows the modelling of surfaces and facilitates their combination with simple operators in the so-called "map algebra".

Literature shows some uses of the raster approach in crime mapping and geographic profiling. Groff and La Vigne (2001) build an overall risk index surface for residential burglaries. Eck et al. (2005) estimate the density of crimes thanks to a continuous surface obtained by interpolation in order to highlight hot spots. Kent and Leitner (2009) integrate rasterized land cover features to enhance JTC models. In identifying the JTC, the solutions in raster mode typically use the construction of cost surfaces, possibly restricted to the road networks. Thus Trotta et al. (2011) generate all possible JTC from the various crime sites to determine the starting point of the criminal with a time constraint. The raster mode was chosen as it gives the possibility to consider each cell as a potential anchor point by contrast to the vector mode which is restricted to the only nodes of the graph.

6.1.4 Operational Aspect of Geographic Profiling Studies

In the current techniques of geographical profiling, the distance from the anchor location to each crime site is unknown. It is often estimated thanks to the analysis of similarly solved crimes in the study area by a classical calibration of a distance decay function or by a Bayesian approach.

But an important limitation of geographic profiling studies is the reliance on solved crime series (Tonkin et al. 2010). First, many authors adopt an inductive approach. They compare the JTCs of several crimes series to compute a distance-decay function instead of performing a proactive deductive analysis. For example, they do not specify how crimes have been connected to the same series.

Secondly, the form of the distance decay function is dependent on the studied area and varies with the scale of analysis (Canter and Hammond 2006). If crime mapping is considered as an essential tool to fight criminality in the United States, most of European polices, with the exclusion of the United Kingdom, are only in the early stages of transposing American methodologies on their own spatial patterns. They do not possess long solved geo-coded crime series for this calibration.

Another criticism made to the calibrated distance function is that it still provides a global approach that neglects the specificities of the individual behaviour whereas mobility characteristics such as the mode of transportation or some environmental preferences may be crucial in delineating a prior search area.

Indeed, studies demonstrated that the variability of intra-offender crime trips is smaller than the inter-offender one, offenders being more consistent with their own journeys than with others for the same crime type (Smith et al. 2009; Lundrigan et al. 2010).

For these reasons, we would like to highlight that every operational investigation can have its own specificities and its own spatial and temporal constraints finding use in geographical profiling.

Behavioural hypotheses can be built on those indications. For example, similar time slots for crimes occurring at different days suggest a constant departure time. In the same vein, successive offences committed the same day suppose a unique JTC. Moreover, all the distances to the unknown anchor point can also be combined as it will be illustrated in this chapter.

This literature review identifies three aspects that have been understudied in geographic profiling: the integration of environmental influence, the opportunities provided by a raster approach and the use of the specificities of an isolated crime series. These aspects are addressed in the study of a real and a-priori unsolved case of criminal investigation.

6.2 Context

Data provided by the police refer to a series of offenses committed by a group of criminals with a single stolen car in the urban area of Charleroi (Belgium) within a short period of time (4 days). The first offence is the theft of the car and the last one

Table 6.1 Summary of the event date/time as given by the Police

Event	Date	Time	Event
1	05/05/30	9:00 am	Car-jacking of the first car
2	05/05/31	4:00 pm	Hold-up at a supermarket
3	05/06/02	7:00 am	Suspicious behaviour in the first car
4	05/06/03	2:00 am	Car-jacking of a second car
5	05/06/03	3:00 pm	Discovering of the first car

is its abandonment. Between these two events, three criminal activities were committed with the same vehicle. Each activity is located in space (mailing address) and time, except the abandonment of the car for which we only know where and when it was discovered by the police (Table 6.1). Thanks to the car owner who remembered the mileage, we are able to estimate the total distance traveled by criminals between the first and the last event (approximately 100 km). This information, that is rare in such cases, is a key element of our methodology.

The purpose of this study is to delineate a withdrawal area where the criminals could hide the car between their activities, by using the chronology and the locations of the five events with the constraint of the known total mileage. The withdrawal area will be based on a subset of road segments selected from all the paths traveled with the vehicle on the road network of the urban region under study.

Belgian police gave us this real case study without informing us of the actual location of the withdrawal site. This allowed us to apply our methodology in real field conditions and to check its accuracy by comparing our results to the reality at the end of the study.

6.3 Data

As the research method is based on the movements of the vehicle, it is necessary to collect and evaluate the information about the road network of the study area at the time of the events. This information is both geometric (axe and width of the road) and semantic (state of the road, traffic direction, *etc.*).

We can obtain the geometry of the network with a sufficient precision for this application, thanks to the different vector spatial databases of the institutional providers of spatial data (e.g. IGN in Belgium).

The geometry is fairly stable in time but the semantic information evolves much faster, especially in urban spaces, without any archive of past modifications (e.g. inaccessible segment because of road-building). Therefore, the earlier the criminal analysis is achieved, the more relevant is the semantic information of the road network.

Belgian Police provided the location of the events with postal addresses. In order to integrate the data of the investigation on the road network, the postal addresses must be transformed in (X, Y) coordinates. Indeed, the localization of the events and the geometrical description of the road network must share the same coordinate system for the analysis (in our case: Belgian Lambert Coordinate System). An automatic geo-codification of postal addresses is possible tanks to the address files provided by private or public institutions. However an interactive localization can be necessary if an address is not available or invalid.

6.4 Methodology

6.4.1 Choice of the Method

When the entire road network is extracted and every event located, the data is ready for the first step of the study: the computation of the shortest path from each event site through the network. In this case, a traditional Dijkstra algorithm would not be pertinent because it would give the shortest path from an event only to the nodes of the graph formed by the network. What we are looking for is the shortest path to every point of the network.

Therefore, we need to use a distance propagation algorithm limited to the road network. This treatment requires working in raster mode by building a cost surface limited to the cells belonging to the network. This implies a preliminary rasterization of the network which is only available in vector mode. The parameters of the transformation "vector to raster" (the resolution of the cells and the extension of the study area) have an important influence on the final results of the procedure. On the one hand, a high resolution and/or a large study area increase the number of cells so that they lead to heavy treatments for the computer. On the other hand, a low resolution diverges from the real dimensions of the studied spatial entities. Moreover the extension of the study area must include the five criminal events and the most probable localizations of the withdrawal site (see Sect. 6.4.4). Therefore, we had to find the best compromise between these parameters. We first tested the treatments explained in the following sections (see Sects. 6.4.2, 6.4.3, and 6.4.4) with a low resolution on a large territory to be able to isolate the most adapted study area. After fixing this first parameter, we tested the treatments with different resolutions on the chosen study area so that we decided to keep a resolution of 20 m on the ground per cell. Indeed, it corresponded to the precision of the initial vector network and computations with a higher resolution risked to become too heavy for the computer.

6.4.2 Building a Cost Surface

We build a cost surface, based on the propagation of distances, for each event considered as a start cell. The principle of the propagation algorithm in raster mode is the following: we propagate a crossing "cost" of the cells, from neighbour to neighbour, from a start cell (a located criminal event of the data) to the borders of the study area. The spread is not isotropic since it is hampered by a friction factor

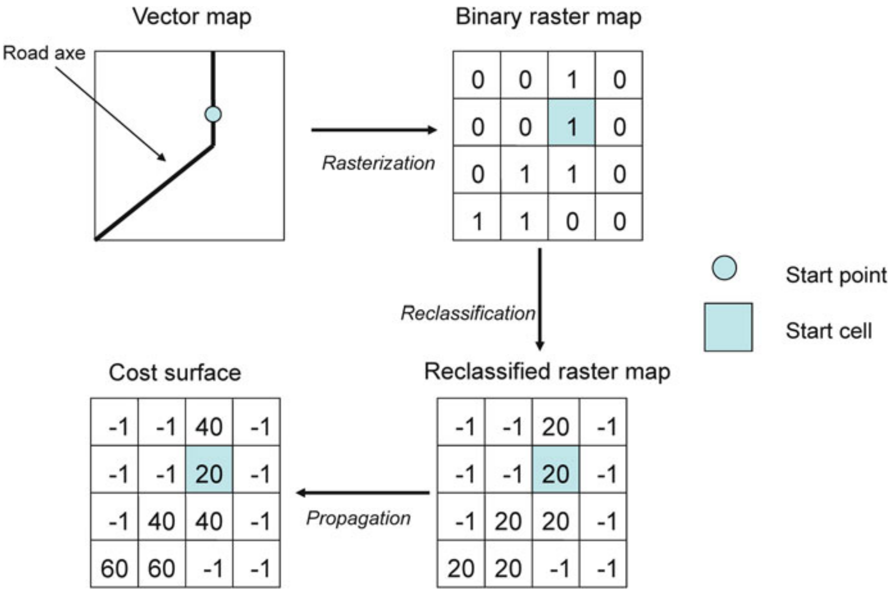


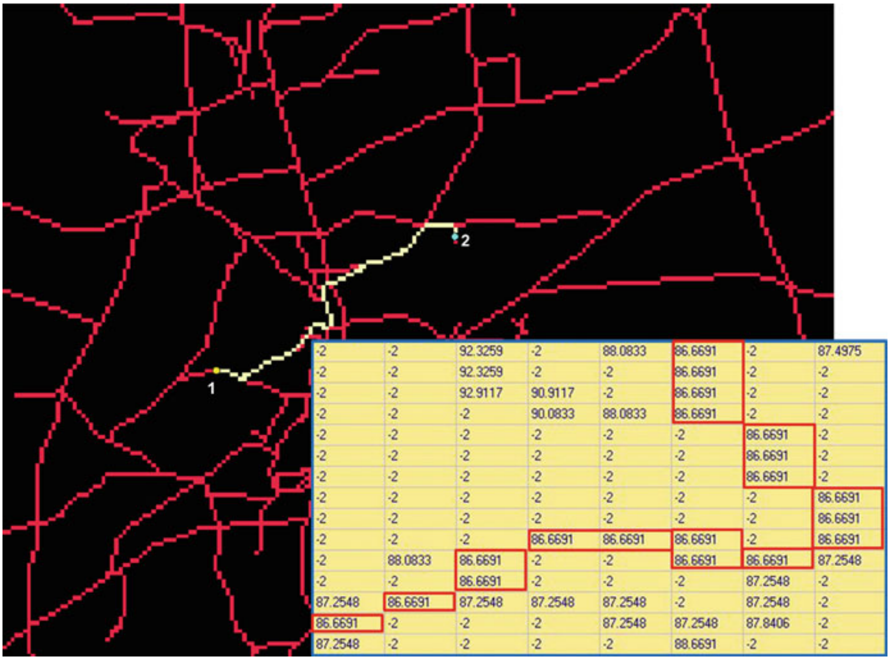
Fig. 6.1 Building a cost surface

in each cell. This factor reflects the difficulty of crossing the cell and, ultimately, the cell can be described as impassable. In the first analysis, the friction of a cell can be considered equal to its length field (or resolution).

Technically, we start with the binary map of the road network that we created by superposing a grid of cells (the size of a cell is 20 m) to the vector data (rasterization). The value of a cell is "1" if it belongs to the road network and "0" if it does not (like every binary image). We reclassify the image to prepare it for the propagation algorithm: the values of the cells become "20" (which corresponds to the resolution of a cell) when they are on the road and they become "−1" when they are off the road. Now we are able to build the cost surface by using the propagation algorithm: from the start cell, each cell's value is cumulatively summed from neighbour to neighbour except the "−1" cells that are considered as impassable by the algorithm (Fig. 6.1).

At the end of the procedure, the cost surface informs us about the cumulated distance required to reach every cell of the network from the starting point. In other words, the value of each cell is the distance between it and the source by following the shortest path along the road network.

This computation is only a first approximation. Indeed, we should take into account imprecision caused by a small map scale (the size of the cells is superior to the width of the road) and the resolution of the cells as a constant crossing friction. Indeed, the precision could be improved with a friction depending on the direction of the crossing. For example, the resolution of the cell is geometrically correct when it is crossed perpendicularly but is equal to $\sqrt{2}*r$ (with r = resolution = cell size) when it is crossed along the diagonal. One way to improve the estimation of friction



-2	-2	92.3259	-2	88.0833	86.6691	-2	87.4975
-2	-2	92.3259	-2	-2	86.6691	-2	-2
-2	-2	92.9117	90.9117	-2	86.6691	-2	-2
-2	-2	-2	90.0833	88.0833	86.6691	-2	-2
-2	-2	-2	-2	-2	-2	86.6691	-2
-2	-2	-2	-2	-2	-2	86.6691	-2
-2	-2	-2	-2	-2	-2	86.6691	-2
-2	-2	-2	-2	-2	-2	-2	86.6691
-2	-2	-2	-2	-2	-2	-2	86.6691
-2	-2	-2	86.6691	86.6691	86.6691	-2	86.6691
-2	88.0833	86.6691	-2	-2	86.6691	86.6691	87.2548
-2	-2	86.6691	-2	-2	-2	87.2548	-2
87.2548	86.6691	87.2548	87.2548	87.2548	-2	87.2548	-2
86.6691	-2	-2	-2	87.2548	87.2548	87.8406	-2
87.2548	-2	-2	-2	-2	88.6691	-2	-2

Fig. 6.2 Shortest path between two events by summing two cost surfaces

per cell is to calculate the average crossing length of the cells belonging to one edge of a road network by dividing the total length of this edge, calculated from the vector data, by the number of cells used for the rasterization of the edge.

The next step is the computation of the total shortest distance to travel to every criminal event in chronological order. If we add two cost surfaces cell by cell, the resulting map informs about the shortest cumulated distance from each cell to the two events. Therefore, the group of cells with the minimum value is logically the shortest path between the two events assigned to the two cost surfaces, and this value is the length of this shortest path (see Fig. 6.2). We repeat this operation with every couple of successive events so that we obtain every shortest path between the criminal events in chronological order. When we sum every value of these shortest paths, the result is the minimum theoretical distance traveled by the stolen car. It cannot be superior to the total mileage traveled by the car (100 km, as provided by the police). The positive difference between this total mileage and the total distance of the shortest paths supports the different scenarios elaborated to locate the possible withdrawal area.

6.4.3 Scenarios Development

Geographic profiling is always based on several assumptions with regard to the offender's spatial behaviour. When multiple hypotheses could describe the events, geographic profiling must be seen as a tool to choose among those possibilities.

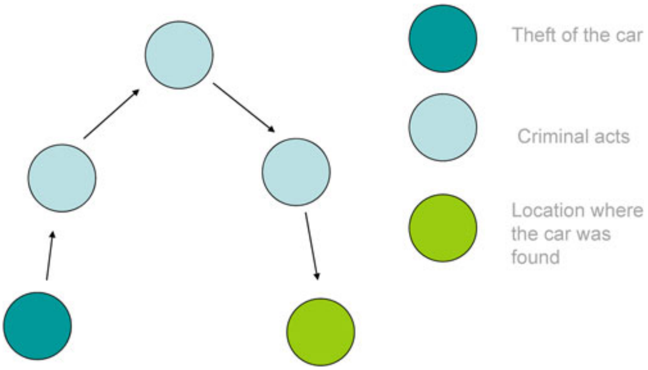


Fig. 6.3 First scenario

In this criminal investigation, several scenarios respecting the total traveled distance have been proposed. They are discussed in detail in this section and the credibility of each of them is estimated thanks to spatial information brought by raster computation and temporal constraints.

The chronology of the events indicates that they did not successively happen during the same day. As soon as we notice a time interval of several hours or even several days between two successive crimes, we can imagine that the criminals came back to the withdrawal site between each couple of consecutive events. Different scenarios can be considered according to the chronology of the facts.

In the sum of the cost surfaces, different weights can be assigned to each event, depending on the number of associated travels. For example, giving a double weight to a specific event means the criminals did a round trip from the withdrawal site to this event instead of a simple one-way trip. Technically, the choice of a scenario can be summarised in the assignation of the weights to the terms of the sum of the cost surfaces.

In the first scenario, which is the simplest one, offenders travel successively from one crime site to another, simply stopping between them for the night when events occur at different dates. Such a hypothesis corresponds to a kind of loop journey that can be easily tested with a geographic information system. In such a situation, the sum of the shortest paths joining each couple of events according to the chronology gives a result of 86 km, which is a too small (<100 km) to validate this hypothesis. A central withdrawal site is then considered as a better scenario for the series (Fig. 6.3).

In the second scenario, the offenders stole the car, came back to the withdrawal site and committed each crime from this site. If two events are close in time, we can imagine that they are successively committed without a ride back to the anchor point. However, it is unclear whether the offenders returned to the withdrawal site after the last criminal event (second scenario). It is plausible that the offenders traveled directly from the final criminal event to the location where the car was found (third scenario). As previously stated, these scenarios condition the way to combine the cost surfaces of each crime site. We attribute a double weight to the

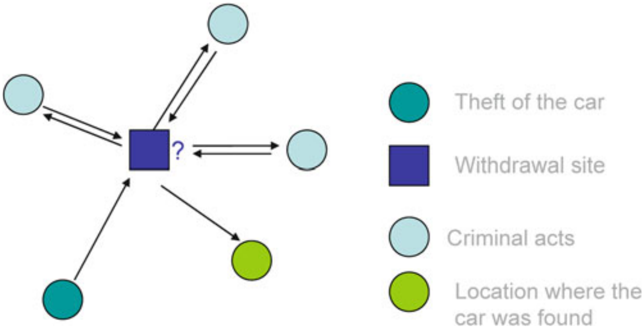


Fig. 6.4 Second scenario

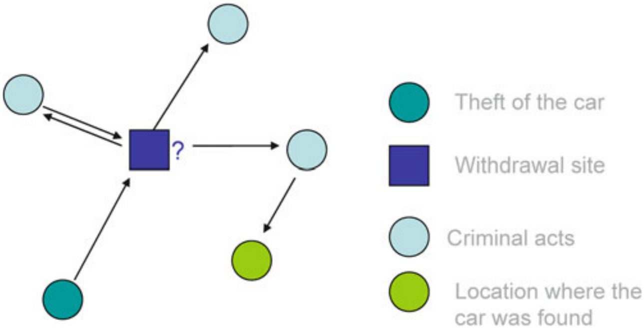


Fig. 6.5 Third scenario

round trips and a single for the others. In the case of the third scenario, the constant distance of the shortest path from the last event to the abandoning of the car is added to every cell of the network (Figs. 6.4 and 6.5).

A fourth scenario can be imagined if we formulate the hypothesis that the criminals did a reconnaissance before the hold-up at the supermarket (second event). The reconnaissance implies a new round trip associated to the second event that the offenders made before the hold-up in order to prepare it. Therefore, we give it a quadruple weight: one round trip for the tracking, and one round trip for the hold-up. When we add the cost surfaces in this way, we notice that the minimum value of the cells of the resulting map is slightly superior to 100 km. That means that with this scenario, we overvalue the total distance traveled by the car. Therefore, we reject the hypothesis of a reconnaissance (Fig. 6.6)

Four scenarios have been imagined based on the distance data and the chronology of events. We already said that the first and the fourth one are not plausible due to the estimation of the total distance traveled by the car (too short for the first scenario, and too long for the fourth one). Therefore, we have to choose between the second and the third one. The only difference between them is an eventual journey to the withdrawal site between the last event and the abandonment of the car. As the police

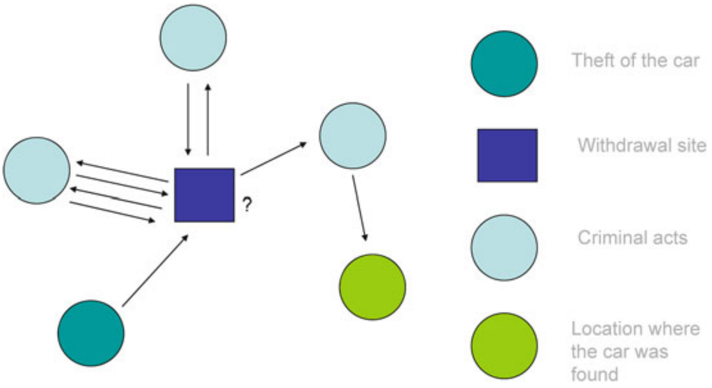


Fig. 6.6 Fourth scenario

told us they found the car only a few hours after the last event (car jacking of a second car), we can therefore consider that the criminals abandoned the car directly after the car-jacking which actually corresponds to the third scenario.

6.4.4 Classification

For the resulting cost surface corresponding to the chosen scenario, we isolate the cells having a value close to 100 km. Indeed, we have to take into account various errors caused by the imprecision of the mileage of the stolen car: the rasterization of the network, the variable accuracy of the geometric and semantic data, the geocodification of the postal addresses, *etc*. Therefore, for a better representation, we classify the map using classes of 5 km around the central value of 100 km. This map gives an idea of the probability of finding the withdrawal site in a cell: the closer to 100 km we get, the more chance we have of finding the withdrawal site (Fig. 6.7).

6.4.5 Multi-criteria Analysis

The search area delimited by the sum of the cost surfaces is still too large to conduct an effective police raid. However, taking into account other factors than the traveled distances will help to reduce this area. This is the aim of the multi-criteria analysis.

6.4.5.1 Generalities

The multi-criteria analysis is a "decision support" method involving various criteria, including the "criterion of scenario" in the final map. The criteria are often

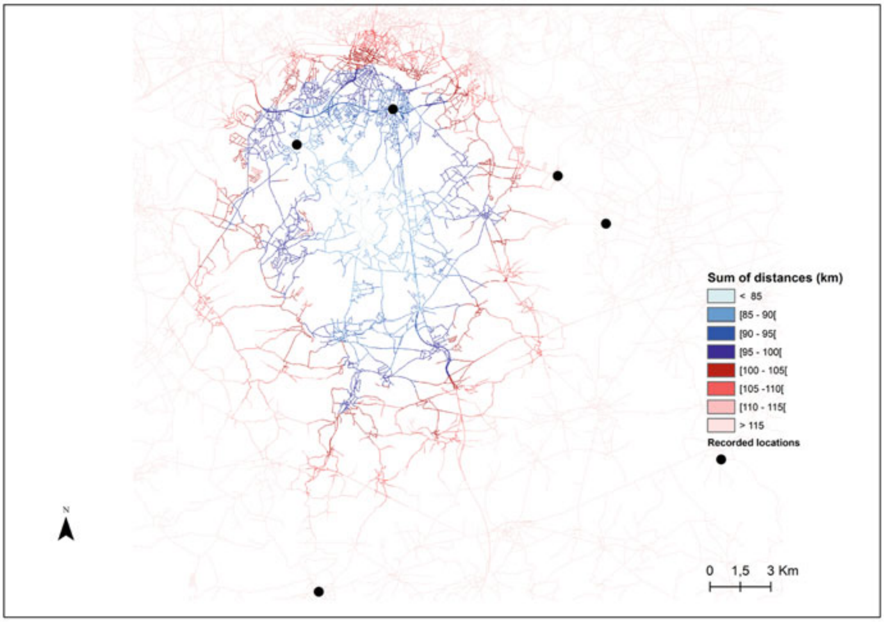


Fig. 6.7 Reclassified sum of the cost surfaces based on the third scenario

heterogeneous, conflicting and with unequal importance. Their combination leads to a performance index associated to each cell which, in our case, is related to the probability of finding the withdrawal site.

To build the index, we use two categories of criteria: judgement and admissibility. A judgement criterion allows us to measure and evaluate an action in regards to its function. This kind of criterion integrates the decision-maker's preferences. It can be positive or negative in the analysis. An admissibility criterion is a constraint limiting the number of actions taken into account. It can allow or forbid a given action (Eastman et al. 1995). First, we calibrate the factors of judgment on the same scale and we give each a relative weight according to the importance given to them by the decision maker. The sum of the weights must be equal to unity and the coherence of relative weight is controlled by the method proposed by Saati (1980). Then we perform the weighted sum of factors between homologous cells of different images containing each judgment criterion. Finally we take the admissibility criteria into account by multiplying the resulting judgement image by the different binary images assigned to the admissibility criteria (Fig. 6.8).

In this present case, we introduce these four criteria:

- A sociological factor taking account of the urban/rural character of the area (judgement criterion);
- A technical factor taking account of the distance to the main roads (judgment criterion);

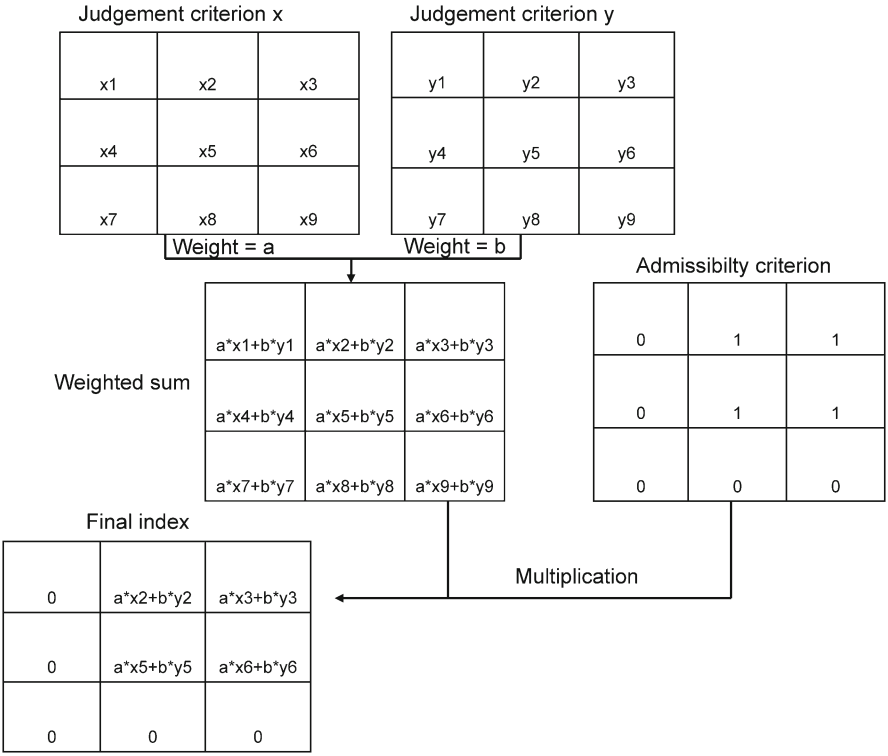


Fig. 6.8 Multi-criteria analysis

- A factor taking account of the chosen scenario, which is actually the result of the summed cost surfaces of the third scenario (judgment criterion);
- A built-up constraint: the withdrawal site must be located in a built-up area (admissibility criterion).

6.4.5.2 Factor 1: Integration of the Rural Character

The first factor gives a score to each commune (the smallest administrative entity in Belgium) relating to its urban/rural character. This character was evaluated with a principal component analysis (PCA). The input variables, provided by the Belgian National Institute of Statistics for the year 2005 for each commune, were the followings:

- percentage of strangers;
- percentage of urban spaces;
- percentage of rural spaces;
- population density;
- average income.

The PCA shows that the first four variables are correlated and can be reduced to a single factorial score explaining the rural character of the communes (the higher the score, the less rural the commune).

We noticed that the PCA was applied on 30 communes in the neighbourhood of the criminal events. This cross-section could seem too small to have reliable results. However, it did not make any sense to extend the territory of this analysis due to the characteristics of rural areas that vary depending on the regions of Belgium. For example, the density of population in rural areas is higher in the north than in the south. We also noticed that due to the commune being the smallest administrative entity of Belgium, it proved impossible to collect more data for the same territory.

Nevertheless, the risk of a PCA based on a small population is mainly influenced by a few individuals that could have very different characteristics from the rest of the group. Therefore, we applied a Jacknife process: the PCA is computed 30 times in total on 29 communes by dropping a commune from the PCA in turn. We noticed that the factorial scores remained relatively identical from one PCA to another. This means that no individual in the population was unique enough to have a major influence on the final result. Thus, despite the small population, we consider the PCA as relevant.

As we formulate the hypothesis that the withdrawal site should be located in a rural space, we create a raster map (still with the same usual resolution) and we allocate the value of the factorial score resulting from the PCA to each cell of every commune.

The only way to compare several criteria is to calibrate them with the same scale. In other words, the minimum and the maximum values of each criterion have to be the same. We arbitrarily chose to encode them in one byte, which means a range of 256 different integer values comprised between 0 and 255. The procedure used to obtain this new range of value is a simple linear transformation described in the following equation.

$$X' = Round\left[\frac{(X - X_{\min})}{(X_{\max} - X_{\min})} * 255\right] \tag{6.1}$$

Where X: original value
X': calibrated value

We observed that the factorial score was decreasing when the rural character was increasing. Keeping in mind that the withdrawal site should be located in a rural area, we have to reverse the range of the rural criteria according to:

$$X'' = 255 - X' \tag{6.2}$$

Where X'': reversed value.

6.4.5.3 Factor 2: Proximity of the Main Roads

We formulate the hypothesis that the withdrawal has to be close to a main road to facilitate an eventual escape of the criminals. Therefore, we have to create a new raster map with a score to each cell increasing with the proximity of the main road.

We start with a binary raster map representing the main roads (the value of a cell is 1 if it covers the road, 0 if not). For each cell of the map, we calculate the distance to the closest main road. The distance is computed by counting the number of cells separating the present cell to the closest road and by multiplying the result by the resolution (20 m). The algorithm returns a new map with a real value for each cell corresponding to the distance to the closest main road. We calibrate it to one byte and reverse the range as we did for the rural factor so that the longer the distance, the lower the chance of finding the withdrawal.

6.4.5.4 Factor 3: Integration of the Scenario

The integration of the scenario implies a particular treatment of the cost surface. The procedure that implements the scenario limits the cost surface to the sole road network. We can admit that the withdrawal site is not located on the road and we must therefore expand the cost surface in the entire territory.

We consider the space outside the network as isotropic so that we can apply the same propagation algorithm (used in Sect. 6.4.2). The propagation starts from the cells located on the network to the cells located perpendicularly of it. The value assigned to a cell located off the road is obtained by adding the value of its closest neighbour belonging to the network to the distance separating the cell from this neighbour.

In order to build the criterion, we reclassify the map resulting from the cost surface. This map represents a range of values comprised between 85 and 115 km. As previously stated, the withdrawal should be located on a cell having a value of 100 km which corresponds to the theoretical distance traveled by the criminals. The values not equal to 100 km were kept to take into account the errors (see Sect. 6.4.4). Therefore, the closer a cell is to 100 km, the greater the chance of finding the withdrawal. The absolute value of the difference to 100 km is calibrated on one byte and reversed to maintain the consistency of the relationship.

6.4.5.5 Constraint: The Withdrawal Must Be in a Built-up Area

The criminals must hide the car inside a garage or a warehouse. Therefore, we use the data from “CORINE Land Cover” (CCE 1993) to extract the built-up area. This vector database stores land use information for the whole of Europe. The different polygons are attributed by a code linked to the “CORINE Land Cover” nomenclature. When we rasterize the data for the studied area, we only keep the polygons which the code refers to a built-up area. The result is a simple binary map: the value of the cells is 1 if they are included inside a built-up area, 0 if they are not.

6.4.5.6 Construction of the Multi-criteria Index

The construction of the final map is realized in two steps. We first combine the three factors and then we apply the constraint.

Table 6.2 Weights assigned to the different factors

Factor	Weight
Factor 1: rural character	0.1
Factor 2: main road proximity	0.2
Factor 3: integration of the scenario	0.7

The combination of the factors is a weighted sum. The weights of each factor, which mean their relative importance in the probability of finding the withdrawal, were arbitrarily fixed with the help of the Police. In other words, the larger the weight, the larger the influence of the factor. Every cell of the three maps is then summed to create a new map representing the combination of these factors. The range covered by the different values of the cells is still the same: integers from 0 to 255 as the sum of weights equals unity (Table 6.2).

We finally apply the constraint to the last map by multiplying it by the binary constraint map. Consequently, the resulting map keeps the values of the combined factors when the cells are included in the built-up areas (the constraint), and displays 0 for the cells outside the built-up area (Fig. 6.9).

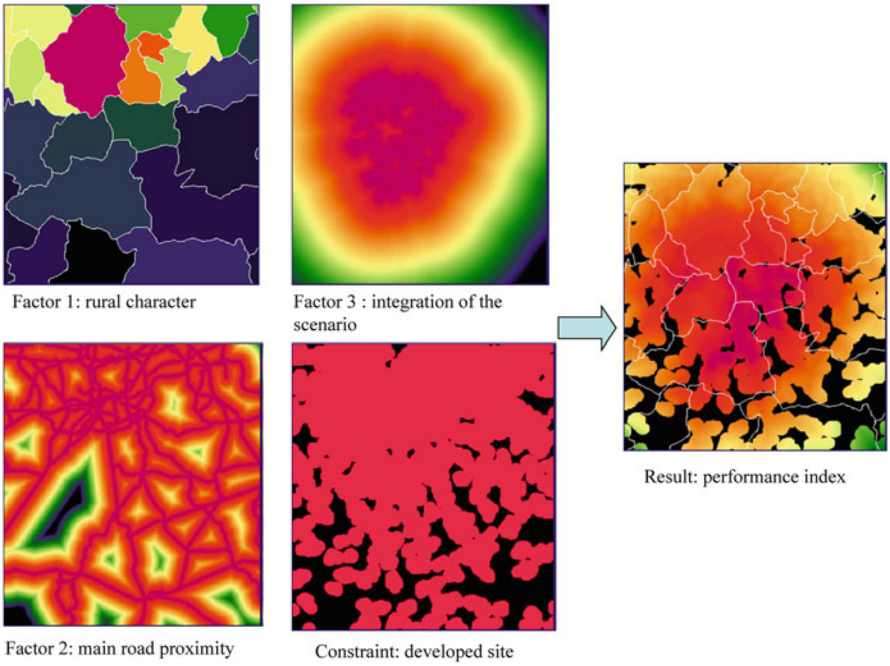
6.5 Validation

After presenting these results to the Police, it appeared that the actual withdrawal site was located on a cell of the final map having the value 252 (the maximum value of the cells is 255). If we classify the map only to keep the cells having a value superior to 251, we can see that only a small stretch of road remains on the map (Fig. 6.10).

6.6 Conclusion

This study referred to a real case provided by the Belgian Police. A series of five events were committed by criminals with a stolen car for which we knew the traveled distance. GIS techniques combined with raster maps allowed us to test the hypothesis that the criminals actually used a withdrawal site during the short time period covered by the events. Indeed, the theoretical distance using the shortest paths along the road network that links each event in accordance with the timeline was actually too short compared to the real one (100 km). Then, several scenarios concerning the movements of the vehicle were devised and evaluated using the total distance factor.

After choosing the most probable one, we delineated the first area for the withdrawal site by selecting the group of cells for which the distance value was close to 100 km in the weighted sum of the cost surfaces of each event. Those cost surfaces resulted from a distance propagation algorithm and the weights of the sum depended



Factor 1: rural character

Factor 3 : integration of the scenario

Result: performance index

Factor 2: main road proximity

Constraint: developed site

Fig. 6.9 Combination of the different criteria

Fig. 6.10 Stretch of road resulting from the reclassification of the final map

on the chosen scenario. Unfortunately, the result covered an area too extensive for a police investigation. In order to reduce it, a multi-criteria analysis was conducted by taking into account various field elements (rural spaces, built-up areas and proximity of the main roads). We finally obtained an area corresponding to a small stretch of road where the criminals actually hid the vehicle, as later confirmed by the police.

Multi-criteria analysis should interest other scientists or police investigators that would like to synthesize several different environmental influences in one probable surface. However, the difficulty remains in properly identifying and weighting those influences. For this reason, working in collaboration with psychologists remains unavoidable.

Moreover, most studies in geographic profiling use behavioural models calibrated with other solved cases of similar crimes. Nevertheless, consistency is more an issue of individual than crime type. This work shows that models built only with data coming from the investigation (especially distance data) can be very useful, even if we must admit that some of them are rarely present (like the mileage of a stolen car).

Another originality of this study is the use of distance along a road network. Indeed, the Euclidian and even better the Manhattan distance is very popular in journey-to-crime, especially in USA. The road networks in American cities follow a very regular structure and can easily be considered as an isotropic space, which is simply incorrect in Europe. If we want to properly understand and model the offender's mobility characteristics, working with street networks is essential.

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