ARTICLE IN PRESS

Computers, Environment and Urban Systems xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

A comparison between the cost effectiveness of CCTV and improved street lighting as a means of crime reduction

Tony Lawson*, Robert Rogerson, Malcolm Barnacle

University of Strathclyde, Glasgow, United Kingdom

ARTICLE INFO

Keywords:
Cost effectiveness
Cellular automaton
CCTV
Improved street lighting

ABSTRACT

The effectiveness of CCTV and improved street lighting has been studied extensively in terms of their potential for reducing the number of crimes in a certain area. However, this does not take into account the cost of the interventions or the savings due to crime reduction. This paper presents a model, which takes the form of a cellular automaton to simulate the implementation of improved street lighting and CCTV cameras using a range of strategies. This permits an exploration of simulated options to find which is most cost effective and what the best strategy for implementation is. The results indicate that there are few situations where CCTV is more cost effective than improved street lighting as a way of reducing street crime. In addition, it is shown that the strategy of targeting locations with the highest crime rates, “hot spots”, has the greatest potential for maximising the cost effectiveness of interventions.

1. Introduction

Situational crime prevention and interventions such as CCTV and improved street lighting are widely used as ways to deter crime. Research is extensive on this but as Cozens and Love (2015) recently note, approaches continually need to adapt with changing demographic patterns, lifestyles and technology. However, adding new approaches and responding to changing urban circumstances is costly for the agencies involved, and difficult choices have to be made between forms of crime prevention. Calls for more sophisticated cost-benefit analysis have been re-iterated by Welsh, Farrington, and Gowar (2015) and in particular, the need for more experimental and quasi-experimental designs to support such cost benefit analysis.

This paper contributes to the debate by developing a model that provides estimates for the effectiveness of CCTV and improved street lighting, quantified in terms of their economic benefits. It also contributes to policy by providing indications of how to use crime prevention measures most effectively, which are robust enough to be generalised into guidelines for designing future crime prevention schemes.

Our approach takes the form of a cellular automaton that will be described in some detail below. The model is used to simulate the implementation of improved street lighting and CCTV cameras using a range of strategies, taking the city of Glasgow as an example. With a population of just over 600,000 Glasgow is the most populous city in Scotland and has one of the highest crime rates in the UK. However, in line with a wider trend in advanced economies, and combined with local initiatives, crime has decreased significantly in recent years. Hence, while all cities have their own unique characteristics, Glasgow presents a suitable test case for modelling urban crime.

The computer simulations permit an exploration of options to find which technology is the most cost effective and what is the best strategy for its implementation. As there is no way to find the optimal strategy by analytical means, a simulation approach is utilised to search among a range of possible alternatives. While the simulations are hypothetical, the model is based on real data. It combines police data on street crimes in Glasgow from 2004 to 2013 with information on the cost per crime from the UK Home Office study of Dubourg, Hamed, and Thorns (2005) and updated estimates from (Home Office, 2011). This makes it possible to determine the total cost of street crime, both economically and socially, for a range of crime types. Next, estimates of the effectiveness of CCTV and improved street lighting, in terms of percentage reduction in crime, are derived from the meta-analyses of Welsh and Farrington (2008a, 2008b). These are used to determine the marginal change in the cost of crime under a range of intervention scenarios. The estimated cost of each intervention is then compared with the anticipated saving, due to the predicted reduction in crime, to obtain a measure of the cost effectiveness of each scheme. This makes it possible to answer questions that are more general such as, under what circumstances is CCTV more cost effective than improved street lighting and what is the best type of location for deploying these resources? Since there are significant areas of uncertainty at each stage of the process, a key feature of the model is

* Corresponding author at: 4/3 14 Haughview Terrace, Glasgow, United Kingdom.
E-mail address: tonylawson773@btinternet.com (T. Lawson).

http://dx.doi.org/10.1016/j.compenvurbsys.2017.09.008
Received 9 December 2016; Received in revised form 13 September 2017; Accepted 25 September 2017

its facility for bracketing each 'best estimate' with a range of values to determine the robustness of the answers to the questions above.

Our simulations show that:

1) There are few situations where installing CCTV is more cost effective than improving the street lighting.
2) Interventions are most cost effective when targeted at highly localised 'hotspots'.

This contributes to the debate on the cost effectiveness of these technologies, provides general guidelines for efficiently implementing crime reduction schemes and presents a modelling tool with the potential for assisting with the design of future interventions.

After this introduction, the paper unfolds as follows. First, the principles of the cellular automaton model are outlined. Then the data requirements for estimating the cost of street crime are discussed. Next, the operation of the model is described in more detail. The initial results from the 'best estimate' model are given next. Then the parameters are varied in a series of 'Monte Carlo' simulations to test the robustness of the results. The implications of the findings are discussed next and conclusions are drawn at the end.

2. Developing the model

The model used in this paper is based on the idea of a cellular automaton. A cellular automaton models a world in which space is represented as a uniform grid, time advances by steps and the laws of the world are represented by a uniform set of rules that are used to compute each cell's state from its own previous state and those of its close neighbours (Gilbert & Troitzsch, 2005). The unit of analysis in a cellular automaton is the individual unit or cell. Minimally, the cell has a location specified by one or more spatial coordinates. The cell may also have other characteristics, which range from a binary on/off indicator to a list of variables. The state of each cell must first be initialised and then it evolves over time according to a set of transition rules. Each cell takes account of its own state and optionally the state of nearby cells. When all cells have been processed, the cycle repeats for the next time step. Time is thus discrete but by simulating small time differences at each step, it is possible to create the impression of continuous evolution.

The agent-based modelling platform NetLogo has a grid of static cells known as patches. These provided a convenient basis for implementing the cellular automaton model. Each postcode in Glasgow was assigned to a spatial location using six-figure UK National Grid map coordinates. The locations of CCTV cameras and streetlights, obtained from Open Data Glasgow and Glasgow City Council respectively, already had x and y coordinates. NetLogo has input functions that were used to load the postcode data to the appropriate patch. There is also a high-level programming language that can efficiently manipulate the data and a graphical user interface where parameters can be set and simulations visualised on a grid. One of the key features of NetLogo for this project was the 'behaviour space' facility that automates the running of many simulations with a range of different parameters. This Monte Carlo method makes it possible to explore the input parameter space, with the results of each combination of parameters output to a spreadsheet. The final model provides a tool that can be adapted to different cities and so with appropriate data, contribute towards optimising the use of resources in any location. The next section describes the model in more detail.

2.1. Data requirements

In order to estimate the cost effectiveness of an intervention to reduce crime, it is necessary to have:

1) An estimate of the average cost of a crime; this can be disaggregated into a number of crime types;
2) Data on actual crimes occurring in a particular area over a specified period;
3) An indication of the effectiveness of CCTV and improved street lighting in terms of the number or percentage of crimes avoided;
4) A way of calculating the total cost of the intervention.

Each of these components is described below.

2.1.1. The unit cost of crime

Estimates for the unit cost of a range of crime types are taken from Dubourg et al. (2005) in conjunction with updated estimates from (Home Office, 2011). These British Home Office reports seem to be the most up to date and comprehensive study undertaken in the UK. They cover the full range of cost components, from precautions against crime, the physical and emotional impact of crime, the value of goods damaged or stolen, costs to the health system, police costs in investigating the crime, the cost of court proceedings and cost to the Prison Service due to any custodial sentence. The values for a range of crime types were obtained from Table 2.1 of Dubourg et al. (2005: 7) and Table 2A (Home Office, 2011: 9).

2.1.2. Crime data

In order to estimate the total cost of crime in a certain area over a specified period, it is necessary to multiply the unit cost of crime by the number of crimes taking place there. Data on street crime in Glasgow was obtained from Police Scotland via collaboration with Glasgow City Council through Community Safety Glasgow. The time window was 1 January 2004 to 31 December 2013 inclusive. Only crimes that occur outdoors are considered because it is assumed that the effect of CCTV and street lighting is negligible for indoor crime. In all, there were just over half a million street crime events over this period, which are observed as crimes at the point when the police refer them for further action by the prosecuting authority, which is known as the Procurator Fiscal in Scotland. Each record contains details of the date and time at which the offence occurred, the nature of the offence and its location at the level of the postcode. On average, a postcode covers about 1 ha.

There are several steps between a crime taking place and being observed in our dataset. First, it must be reported to the police. Next, the police have to record it as a crime. Then the crime must be solved or detected i.e. the offender is identified. This means that to estimate the actual cost of street crime, it is necessary to extrapolate from the dataset we have in order to estimate the true number of offences that actually took place.

2.1.3. Reporting and recording crime

For most types of crime, the multiplier up to the point of the police recording it was obtained from Table A1 in Home Office (2011: 8). For other types that were not available from the Home Office report, the rate of reporting to the police was taken from ONS (2012) and the rate of recording by the police was obtained separately from HMIC (2014: 64).

2.1.4. Detecting crime

The rate of detection of offences was taken from Table 2 of Smith, Taylor and Elkin (2013: 25). The percentages do not vary greatly from year to year and these values are from 2008/9, which corresponds to the middle years in our dataset.

2.2. Crime multiplier

The proportion of crime reaching the next stage of the process can be interpreted as a probability. If these are assumed to be independent events then the probability of a particular crime that occurs being detected, where it is observed in our dataset can, be obtained by multiplying the probability at each stage. Multiplying the number of crimes

Table 1
Crime multiplier and unit cost.

Type of offence	Reported to Police	Recorded by Police	Detected	Multiplier	Unit cost of crimes £ (2015 prices)
Other	0.39	0.67	0.72	5.32	404
Homicide	1		0.94	1.06	1,970,840
Serious Wounding	0.631		0.41	3.87	28,678
Sexual Offences	0.089		0.30	37.45	41,391
Common Assault	0.128		0.38	20.56	1943
Robbery	0.223		0.21	21.35	9796
Burglary	0.380		0.16	16.45	4372
Theft	0.33	0.83	0.18	20.28	1133
Theft not Vehicle	0.33	0.83	0.11	33.19	849
Theft of Vehicle	0.787		0.14	9.08	5536
Theft from Vehicle	0.303		0.09	36.67	1151
Attempted Vehicle Theft	0.440		0.11	20.66	686
Criminal Damage and Arson	0.184		0.14	38.82	1170

Notes: Our crime data is pooled over the years 2004 to 2013. However, since crime rates have been falling in Glasgow during this period, about half the crimes took place before the end of January 2008 and half after that. Hence, the unit cost of crime has been uprated to 2008 from the 2003 valuations of Dubourg et al. (2005) using updates for 2011 from Home Office (2011). The unit cost of crime is set to 2008 prices for all categories except "violence", "wounding", "theft" and "other" for which updated estimates were not available from Home Office (2011). These were obtained for 2008 by simple linear interpolation between the 2005 and 2011 values. After this, all costs were uprated to 2015 prices using the change in the Consumer Price Index between 2008 and 2015.
Theft is a general category that may include other types of 'theft' so the other theft categories are not exhaustive.
The cost of "Criminal Damage and Arson" is difficult to assess because, more than for the other crime types, there is a large variation in the cost of this crime, from a few pounds to millions of pounds in the case of a large fire.

observed in our dataset by the reciprocal of this probability then gives an estimate for the number of street crimes that actually took place. This is done using the 'multiplication factor' in Table 1, which summarises the above process.

Table 1 shows, for each type of crime considered in Dubourg et al. (2005) the proportion reported, recorded and detected. It then gives the calculated crime multiplier and unit cost of crime. Since the different surveys classify crime types differently, some of the values in the 'recorded' and 'detected' columns were used across similar crime types. The recording probabilities for theft and some of the violent offences are applied to a range of different crime sub-types; as is the rate of detection for some of the other crime types.

Some crimes are present in our dataset but cannot easily be allocated into one of the crime types in Table 1. These include fraud and forgery as well as drug offences and consuming alcohol in a prohibited area. In order that the total cost of street crime includes these offences, they have been collected into an 'Other' category. The problem then remains of allocating an average cost for this type of crime. Since, in many of these cases, there is no identifiable individual who is the victim of these crimes, factors such as emotional and physical impact will not be present. However, there would, at least be a cost to the criminal justice system. In view of this, a nominal value of £404 in 2015 prices was applied which is the uprated cost of a non-vehicle theft from Table 2.2 of Dubourg et al. (2005).

2.3. The effectiveness of CCTV and improved street lighting for reducing street crime

The previous two sections were concerned with estimating the cost of street crime. This section uses the available literature to assess what can be done to prevent crime using CCTV and street lighting.

2.3.1. CCTV

Isnard (2001: 5) lists several goals for surveillance camera systems.

- To reduce crime
- To reduce the fear of crime
- To improve public safety
- To improve property security
- To create a safe and vibrant place for the leisure and pleasure of the people of, and visitors to, the public space
- To ensure that persons such as the elderly, the disabled, women and indigenous peoples, can use the public space safely.

Some of the rationale for the use of CCTV can be supplied by Routine Activity Theory (Cohen & Felson, 1979). Crime is supposed to occur when a potential victim and a motivated offender meet in the absence of a capable guardian. The potential offender's awareness that they may be being watched increases the perceived risk of offending at this particular location and so decreases the motivation to offend. Apart from this deterrence effect, other justifications for the use of CCTV include the efficient deployment of police to areas where there is criminal activity taking place or likely to take place and that the photographic evidence eases detection (Woodhouse, 2010).

Perhaps the most comprehensive survey of the effectiveness of CCTV for crime reduction is the meta-analysis of 41 CCTV schemes worldwide by Welsh and Farrington (2008a). Analysis is restricted to those studies that have prior and post intervention crime measures and at least one control area. The effect of the intervention is standardised across studies using the 'relative effect size' (RES) measure. This is defined as:

$$\text{RES} = a{*}d/b{*}c$$

where:

a is the number of crimes in the experimental area before the intervention;
b is the number of crimes in the experimental area after the intervention;
c is the number of crimes in the control area before the intervention;
d is the number of crimes in the control area after the intervention.

The weighted average RES for all 41 studies is 1.19, which is equivalent to a reduction of 16% in the experimental area compared with the control area. However, CCTV only seems to be effective in the UK where the average RES of 34 studies is 1.24, corresponding to a 19% reduction. The seven studies outside the UK have an average RES of 0.97, corresponding to a 3% increase in crime. CCTV also seems to be more effective in well-defined areas such as car parks, which saw a RES of 2.03 or a 51% reduction, and public transport with a RES of 1.3, which is equivalent to a 23% reduction. There is also a differential effect on crime types. For vehicle crime, the RES was 1.35 implying a reduction of 26%, while for violent crime the RES was 1.03 or a 3% reduction. The only study included in Welsh and Farrington (2008a) that took place in Scotland is that of Hood (2003) which had a RES of 1.43 corresponding to a 30% drop in crime. However, these encouraging results were not found in a wider scheme in Glasgow reported by Ditton (1999).

Despite the existence of some successful schemes as noted here, considerable doubt surrounds the effectiveness of CCTV as a crime prevention measure. Some of the explanation for this may be that few schemes reach the level of statistical confidence that is sufficient to reject the null hypothesis that CCTV has no effect on crime rates. It may be speculated that the reason for this is due to the spatial distribution of crime itself. Our studies of crime in Glasgow confirmed what had been observed before by Eck, Clarke, and Guerette (2007), which is that crime is highly concentrated in 'hotspots'. If an experimental or control area contained a crime hotspot, changes in that area would increase the variance of observed crime rates and so decrease the power of the statistical test to reject the null hypothesis. It is also important to note that these schemes had CCTV as the main component of an intervention that involved other features such as improved lighting. Hence, the effect of CCTV alone is not known. Several commentators such as Davies (1997) and Dee (2000) remain unconvinced of the efficacy of CCTV as a crime prevention measure and express concerns about its implications for privacy and surveillance.

2.3.2. Street lighting

Unlike CCTV, street lighting is usually deployed for reasons other than preventing crime. One of the reasons for thinking that improved street lighting might lower crime rates is that the offender is more visible and this increases the risk of detection. However, it has been found that daytime crime falls by the same amount as night-time crime when street lighting is improved (Welsh & Farrington, 2008b). This can be explained by the idea that improved street lighting increases community cohesion, which in turn counteracts criminal behaviour.

Welsh and Farrington (2008b) conducted a systematic review of the effect of street lighting on crime using a similar methodology to their CCTV study. This makes it very useful for comparing the two approaches. Their meta-analysis of 11 crime reduction schemes based on improved street lighting found a RES of 1.27 overall, which is a reduction of 21%. Schemes in the US had a RES of 1.08 or a 7% reduction. In the UK, the average RES was 1.62 or a 38% reduction. Improved street lighting is more effective against property crime with a RES of 1.2, which is a 17% reduction, compared to violent crime with a RES of 1.1, indicating a 9% reduction.

While some early studies into the effectiveness of street lighting as a crime reduction measure were inconclusive (Tien, O'Donnell, Barnett, & Mirchandani, 1979), later investigations such as Pease (1999: 68) concluded that 'the capacity of street lighting to influence crime has now been satisfactorily settled'. More recently, Welsh and Farrington (2008b: 3) noted that 'improved street lighting significantly reduces crime'. Improved street lighting does not have the same privacy implications as CCTV but there are concerns that inappropriate street lighting can reduce visibility due to glare, interferes with sleeping patterns and wildlife, as well as obscuring our view of the night sky (Commission for Dark Skies, 2015).

2.4. The cost of CCTV and street lighting

2.4.1. CCTV

Gill and Spriggs (2005) provide detailed costings for 14 CCTV schemes in the UK. Table 2 below shows a summary of costs derived from Table 5.3 in Gill and Spriggs (2005: 105). In Table 2, the location is given first then the number of cameras in the scheme. The initial set-up cost is shown next, then the annual running cost. The last two columns show these costs per camera. They were obtained by dividing the set-up and running costs by the number of cameras and multiplying by 1.55 to uprate their 1999 based estimates to 2015 valuations using the UK Consumer Price Index.

Table 2
Cost of CCTV schemes.

Location	Number of cameras	Set-up cost (£)	Ongoing cost (£)	Installation cost 2015 per camera (£)	Annual running cost in 2015 per camera (£)
City Outskirts	47	733,053	79,269	24,175	2614
Hawkeye	646	3,381,572	326,466	8114	783
City Hospital	9	70,105		12,074	–
South City	51	1,231,160	152,834	37,418	4645
Shire Town	12	166,415	16,935	21,495	2187
Market Town	9	167,674	13,082	28,877	2253
Borough Town	40	286,814	22,056	11,114	855
Northern Estate	11	216,496	49,018	30,506	6907
Westcap Estate	12	181,071	35,857	23,388	4632
Eastcap Estate	10	198,791	44,520	30,813	6901
Dual Estate – A	5	56,891	10,280	17,636	3187
Dual Estate – B	5	43,237	10,282	13,403	3187
Borough	8	97,065	31,191	18,806	6043
Deploy Estate	11	326,610	47,159	46,022	6645
Average				**23,132**	**3911**

It can be seen from Table 2 that the initial set-up cost per camera is highly variable from £8114 to £46,022. The annual running costs range from £855 to £6907 per camera. Based on these values, the average installation cost per camera is £23,132 and the average annual running cost is £3911. Since there are no running costs for the City Hospital scheme, the running costs were averaged over the 13 schemes for which this information was available.

2.4.2. Street lighting

Several factors are involved in determining what constitutes good street lighting and so what constitutes an improvement in street lighting. First, it has to be of the appropriate brightness for its purpose. Beyond that, light should be directed only to where it is needed to avoid glare. It should also be energy and cost efficient. The improved street lighting schemes described in Welsh and Farrington (2008b) only record the increase in the intensity of light in the scheme area. Hence, for the purposes of this paper, improved street lighting will be defined as having brighter lights than were there before. Of the 13 schemes described in Welsh and Farrington (2008b), six do not indicate the amount by which the lighting intensity was increased. The others are expressed in multiples of the pre-existing lighting of $4\times$, $7\times$, $2\times$, $3\times$, $2\times$, $2\times$ and $5\times$. The average brightening is therefore 3.57 times and this will serve as our working definition of improved street lighting. It will be assumed that the other factors do not worsen as a result of brightening the street lights.

Schemes to upgrade street lighting can include three components. One is to upgrade the lantern (or luminaire) which includes the bulb itself, as well as the electrical connection and covering. The lamppost may be changed at the same time, and another option is to increase the number of streetlights.

2.4.2.1. Cost of street lighting upgrades. If the lantern is one of the conventional types of high-intensity discharge lamps, this may be done by replacing it with a one that has a higher power rating. Alternatively, it can be changed to a Light Emitting Diode (LED), which can produce more light with a lower power consumption. A report from Scottish Futures Trust (2016) provides some examples of the type of LED streetlight needed to replace a conventional light of the same brightness. These are shown in Table 3. Cost estimates were obtained from fluxledtrade.com in 2015 prices.

There is likely to be some variation from these values depending on the circumstances of particular cases. In addition, there is the labour

Table 3
Example LED replacements for conventional lighting.

Original lighting	Equivalent LED replacement	Percentage reduction	Unit cost (£)
70w SON	30w LED	57%	196
90w SOX	56w LED	38%	298
100w SON	56w LED	44%	298
125w MBFU	30w LED	76%	231
135w SOX	56w LED	59%	299
150w SON	122w LED	19%	333 (140w)
250w SON	84w LED	66%	362
400w floodlights	122wLED	70%	333 (140w)
Average efficiency saving		**54%**	

SON (high pressure sodium).
SOX (low pressure sodium oxide).
MBFU (mercury fluorescent bulb).
(The wattages in brackets indicate that a more powerful bulb was used).

cost of installation, which can be estimated at £50 based on two people taking half an hour to complete the work.

The majority of the running cost of street lighting is due to the cost of the electricity used. For each postcode, this is defined by the formula:

$$c = w*t*p$$

where:

c is the cost of lighting the postcode for 1 year
w is the total power usage of streetlights in the postcode in kilowatts
t is the number of hours the lights are on in 1 year
p is the price of electricity for 1 kW h

The cost of maintenance is assumed to be unchanged following the upgrade.

2.4.2.2. Street lighting improvement schemes. In principle, it is only necessary to change the lantern to improve the street lighting but in many cases, ageing lampposts are replaced and additional lampposts are added as part of a lighting upgrade. This was the case in the scheme described in Painter and Farrington (1999) at Stoke-on-Trent, UK. Here, the old street lighting was replaced with 110 new streetlights and some nearby footpaths were also lit. The cost of this intervention was £77,071 which is £701 per streetlight in 1992 prices. In Painter and Farrington (1997), the scheme in Dudley, UK involved the installation of 129 new streetlights to replace the old ones. The cost here was £55,000 which is £426 per streetlight.

More recently, a range of major street lighting upgrade schemes have been implemented by local authorities which often involve replacing the lighting with LEDs. The aim here is usually to reduce spending on electricity and maintenance, and so recoup the cost of the scheme. East and West Dumbartonshire Councils, between them, converted 36,000 street lights to LEDs for £13.2 million (Scottish Futures Trust, 2013), a cost of £367 per street light. Salford City Council upgraded 24,000 lights at a cost of £13.8 million which included £3 million for replacing lighting columns and £9 million for new lanterns, at an overall cost of £575 per streetlight. Birmingham City Council replaced 42,000 street lighting columns (lamppost and lantern) for £70 million at £1667 each (ibid). These schemes involve various combinations of upgrading the lantern, lamppost and adding new lights. However, they all essentially build upon lighting infrastructure, such as the underground cabling, that was already present. Constructing new lighting in a place that was not lit previously would clearly be more expensive and since this option seems to be unusual in practice, it will not be modelled here. Hence, the conclusions of this paper only apply to situations where the lighting upgrade can build upon existing infrastructure.

2.4.3. Current CCTV and lighting infrastructure

The hypothetical simulations of measures to reduce crime are to be built on top of the existing CCTV and street lighting infrastructure that is already present in Glasgow. This is because the observed crime in our dataset has presumably been influenced by the existing street environment and the aim is to find the marginal change in crime due to the interventions to reduce it. In addition, we do not want to place CCTV cameras on sites that are already occupied or increase street lighting in areas that are already well lit.

Data on the number and postcode location of the 399 CCTV cameras that were present in Glasgow during the period from 2004 to 2013 were obtained from Community Safety Glasgow (2015). The location and type of the around 64,000 streetlights in Glasgow were provided by Glasgow City Council. The power requirements of these lights were obtained from the type of lantern used, as in Table 3 above.

3. Cost comparison

With all the data in place, the next problem is to simulate a range of intervention scenarios to search for the most cost-efficient options. This could be done using a spreadsheet formula for each postcode such as:

$$\begin{aligned}\text{Total saving} = &(\text{cost of crime before the intervention}\\ &- \text{cost of crime after the intervention})\\ &- \text{cost of the intervention}\end{aligned}$$

where: the cost of crime is the number of crimes of each type multiplied by the unit cost of each crime. However, there are 14,771 postcodes in Glasgow, and this is multiplied by 16 crime types, plus total crime, and there will be many different combinations of CCTV and lighting scenarios to test so that using a spreadsheet model would become impractical. For this reason, a simulation method known as a cellular automaton was used which represents the postcodes spatially. The software provides a set of routines to store data for each one and manipulate it using a high-level programming language. This approach is described in more detail in the next section.

3.1. Spatial crime model

3.1.1. Initialisation

A text data file is read in which contains the following variables for each postcode in the City of Glasgow. The variables are listed in Table 4.

A range of other parameters can be set before beginning a simulation; central among these are the percentage reductions in crime due to CCTV and improved street lighting derived from Welsh and Farrington (2008a, 2008b). These are summarised in Table 5.

Other important parameters are the unit costs of crime, the estimated average costs of installing and running CCTV cameras from Gill and Spriggs (2005) as well as the cost of streetlighting improvements from the examples described in Section 2.4.2.2 above. Finally, the number of postcodes in which to improve the streetlights or install additional CCTV cameras is set.

3.2. Running simulations

3.2.1. Baseline scenario

With the data loaded and initial parameters set, the simulation can be started. If the number of CCTV cameras required is set to its current value of 399 and the number of postcodes in which to improve the lighting is set to zero, the cost of crime is modelled at the average annual rate for the period from 2004 to 2013. Taking multiple years reduces the number of postcodes that have zero recorded crime. This is the baseline or 'no change' scenario against which the effect of interventions is to be measured. Alternative baselines could be set-up by preparing a different input data file, such as starting with the most

Table 4
Input parameters for the street crime model.

Field name	Contents
Pc	Postcode
X	Map x coordinate
Y	Map y coordinate
Outcode	City postcode district
Cctvs	Number of CCTV cameras in postcode
Pubs	Number of public houses in postcode
SIMD	Scottish Index of Multiple Depravation
Lighting	Average artificial lighting in lumens per square metre
Crimes	Number of crimes at postcode (2004–2013)
Density	Population density at postcode
PCcost	Total cost of crime at the postcode
crimes0	Number of other crimes
crimes2	Number of homicides
crimes4	Number of woundings
crimes6	Number of sexual offences
crimes7	Number of common assaults
crimes8	Number of robberies
crimes9	Number of domestic burglaries
crimes10	Number of thefts
crimes11	Number of non-vehicle thefts
crimes12	Number of vehicle thefts
crimes13	Number of thefts from a vehicle
crimes14	Number of attempted vehicle thefts
crimes15	Number of criminal damage, vandalism, fire raising
crimes16	Number of rapes
lightpower	Total wattage of street lights
Lights	Number of streetlights in postcode
Lighttype	Type of street lighting in postcode (conventional/LED)

Table 5
Crime reduction parameters.

	RES	Percentage reduction
CCTV (Welsh & Farrington, 2008a: 72)		
Vehicle crime	1.35	25.93%
Violent crime	1.03	2.91%
Other UK crime	1.24	19.35%
Street lighting (Welsh & Farrington, 2008b: 48, 49)		
Property crime	1.20	16.67%
Violent crime	1.10	9.09%
All crime	1.27	21.26%

Notes: For the purposes of this study, violent crime consists of homicide, serious wounding, sexual offences, common assault, and robbery. Vehicle offences include theft of a vehicle, theft from a vehicle, and attempted theft from a vehicle. Property offences include burglary, theft, non-vehicle theft, and criminal damage including arson.

recent year instead of a longer-term average.

3.2.2. Intervention scenarios

The aim of the model is to estimate the savings and costs of a range of possible CCTV and street lighting interventions that aim to reduce crime. Five strategies are considered in the examples described here which are:

'Random' place CCTV or lighting at random postcodes throughout the city.
'Dimly Lit Areas' intervention begins in the least well-lit postcode and continues into successively brighter postcodes until the required number of fixtures have been upgraded. The 844 postcodes (5.7%) that have no street lighting are not included in this option. As discussed above, the lack of infrastructure in these areas would incur additional costs which would be dependent on local conditions and be difficult to estimate accurately.
'Hot Spots' intervention operates from the postcode with the highest crime rate and proceeds to those with lower crime rates.
'Public Houses' place CCTV or improved street lighting in a postcode that contains an inn. If all of these locations have been covered, any further interventions are placed in a nearby postcode.
'Deprived Areas' scenario places the first intervention in the most deprived area, defined as the one that has the lowest Scottish Index of Multiple Depravation (SIMD) score. As the most deprived areas are covered, subsequent interventions move to progressively less deprived areas.

It is also possible to vary the number of fixtures to install in order to investigate the effectiveness of schemes of different sizes.

3.2.3. Variable parameters

Each step in the process of developing the model described above introduces some level of uncertainty or error into the results. The estimation of the number of street crimes occurring from police reports, the cost of each crime, and the effectiveness of CCTV and lighting at reducing crime are not known exactly. In addition, the cost of CCTV and street lighting is highly variable and introduces more uncertainty into the results. Moreover, it is not possible to determine the distribution of errors so that confidence intervals could be determined.

Although the amount of uncertainty in the point estimates of crime costs is not known, it is possible, to run a set of simulations to determine under what conditions the technologies of CCTV and street lighting become equally cost effective. Then, based on the literature above, to make an assessment of the plausibility or likelihood of the combination of parameters needed to achieve this.

Table 6
Estimates of the average number and cost of street crime annually in Glasgow between 2004 and 2013.

Type of crime	Observed number of crimes per year	Multiplier	Projected number of crimes per year	Unit cost of crime (£ 2015)	Annual cost (£ millions)
Criminal damage & arson	8121.77	38.82	315,287	1170	368.886
Sexual offence	141.76	37.45	5309	41,391	219.741
Common assault	5278.88	20.56	108,534	1943	210.921
Robbery	594.24	21.35	12,687	9796	124.287
Serious wounding	1047.75	3.87	4055	28,678	116.283
Theft of vehicle	2243.52	9.08	20,371	5536	112.784
Other	28,405.00	5.32	151,115	404	60.997
Theft	2122.80	20.28	43,050	1133	48.757
Homicide	12.52	1.06	13	1,970,840	26.162
Theft from vehicle	562.01	36.67	20,609	1151	23.727
Attempted vehicle theft	485.53	20.66	10,031	686	6.878
Theft – not vehicle	212.79	33.19	7063	849	5.999
Burglary in a dwelling	53.79	16.45	885	4372	3.869
Total	**48,010.10**		**699,009**		**1329.291**

4. Results

4.1. Baseline

The cellular automaton model was run with the best estimate values derived above. Table 6 shows the estimated number of street crimes annually and total cost for a range of crime types.

In Table 6, the 'Observed Number of Crimes per Year' gives the average number of crimes annually from 2004 to 2013 which was obtained from Police data. The 'Multiplier' (from Table 1 above) is used to estimate the 'Projected Number of Crimes per Year' that actually took place. This is multiplied by the 'Unit Cost of Crime' (also from Table 1) to obtain the average 'Annual Cost' of crime.

The cellular automaton performs this calculation on each postcode then aggregates the results for each crime type. The results in Table 6 were also obtained by adding up the observed number of crimes for each crime type and calculating the table values manually. Agreement between the figures forms a useful test of the program code.

Table 6, shows our estimate that there were, on average, nearly 700,000 street crimes in Glasgow per year from 2004 to 2013 incurring an average annual cost of over 1.3 billion pounds. Criminal damage including arson was both numerically and financially the largest category.

4.2. Scenarios

The marginal change in the cost of crime can now be estimated by adjusting the crime rate in selected postcodes (depending on the strategy chosen) by the average effect of the schemes reported in Welsh and Farrington (2008a, 2008b).

Tables 7 and 8 show the projected effect of some hypothetical interventions to reduce street crime. Table 7 compares the effect of adding 26 new CTV cameras to the current 399, against the effect of improving street lighting in 100 postcodes. The larger CCTV schemes in Table 8 add 601 cameras to the current 399, making the total number of CCTVs up to 1000. The lighting intervention in Table 8 increases the brightness in 1000 postcodes. In each table, the five intervention strategies identified above are tested.

In each case, a postcode is deemed to be covered if it has one CCTV camera or the average brightness of the postcode reaches 100 lm per square meter. This is about the brightness of an overcast day and is equal to the brightest few postcodes currently. Each scenario operates for a nominal ten years, which is assumed to be an appropriate life span for the infrastructure investment, after which it would need to be significantly upgraded or replaced. Each of the Tables 7 and 8 show the installation cost in the first year and the total cost of installing and operating the scheme over ten years. Savings are calculated by subtracting the revised cost of street crime in each year from the cost of crime projected in the absence of any intervention, which is the baseline scenario described above. All values are in millions of pounds.

Table 7
The cost effectiveness of small to medium sized crime prevention schemes.

Strategy	Increase from 399 to 425 CCTV cameras			Improve street lighting in 100 postcodes		
	Initial cost	Total cost after 10 years	Savings due to crime reduction	Initial cost	Total cost after 10 years	Savings due to crime reduction
Hotspots	0.601	1.618	50.259	0.136	− 0.050	161.400
Random	0.601	1.618	2.400	0.112	− 0.021	10.092
Deprived areas	0.601	1.618	1.167	0.114	− 0.009	11.153
Public houses	0.601	1.618	2.329	0.111	− 0.054	9.363
Dimly lit areas	0.601	1.618	3.101	0.138	− 0.015	6.599

Table 8
The cost effectiveness of large crime prevention schemes.

Strategy	Increase from 399 to 1000 CCTV cameras			Improve street lighting in 1000 Postcodes		
	Initial cost	Total cost after 10 years	Savings due to crime reduction	Initial cost	Total cost after 10 years	Savings due to crime reduction
Hotspots	13.902	37.407	358.068	1.238	− 0.259	595.245
Random	13.902	37.407	54.920	1.176	− 0.224	115.228
Deprived areas	13.902	37.407	56.157	1.159	− 0.124	107.337
Public houses	13.925	37.787	54.869	1.051	− 0.676	101.170
Dimly lit areas	13.902	37.407	42.459	1.301	− 0.243	81.780

It is apparent from Tables 7 and 8 that the strategy of targeting crime hotspots generates more savings for both CCTV and lighting interventions than any of the other strategies. For the CCTV schemes in hotspots, the savings are almost ten times the investment for large schemes while the lighting schemes generate greater savings for practically no net cost. In the other strategies, CCTV schemes repay around 135% of the investment while the streetlight improvement schemes all have savings that greatly exceed the costs. Negative costs are possible for the lighting schemes due to electricity savings in converting from conventional to LED.

4.3. Variable parameters

These results can only be indicative because, as noted above, there are many sources of error and it is not possible to determine the size or distribution of the errors. A Monte Carlo simulation running many alternative scenarios with different parameters addresses this problem. The objective is to improve the performance of CCTV schemes and degrade the performance of lighting schemes to determine the extent to which their parameters would have to change to make their performance comparable. As both CCTV and lighting schemes appear to be most effective in crime hotspots, all tests below use this strategy.

Thirty-two variations of CCTV parameters were tested. Here, the effectiveness of CCTV in preventing street crime for vehicle, violent, and other crime was doubled to 51.9%, 5.8% and 38.7% respectively. This compares with the upper 95% confidence bound found by Welsh and Farrington (2008a: 72) of a RES of 1.39, which corresponds to a 28% reduction in crime overall. The cost of installing and running each camera was set to the cheapest example reported by Gill and Spriggs (2005) which is £8114 and £855 respectively.

128 variations of street lighting parameters were implemented. In these, the percentage reduction in crime for violent, property, and other offences was halved to 4.5%, 8.3% and 10.6% respectively. The lower 95% confidence interval for street lighting in Welsh and Farrington (2008b: 50) is a RES of 1.07 or a 6.5% reduction for all crime. The cost of installing new lighting was increased by a factor of five from its original value. This was simulated as the cost of a 122w LED lantern as in Table 3 which is (£333 $*$ 5) + £50 = £1715. This is slightly more than the £1667 of the most expensive per fixture scheme mentioned in Section 2.4.2.2, which included a mixture of new lanterns, lamp posts and new lighting.

It was also assumed that the efficiency saving due to converting from conventional to LED lights is reduced to zero. Since uncertainty in estimating the level of crime can be expected to affect both CCTV and

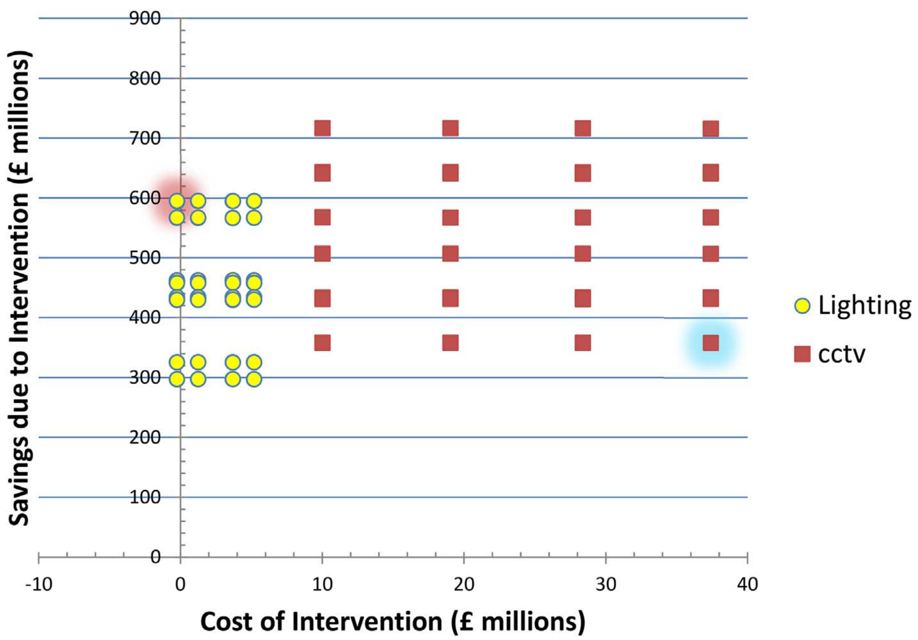

Fig. 1. Costs and benefits of a range of CCTV and lighting schemes. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

lighting schemes in a similar way, the best estimate values for the amount and type of crime remain the same. The results of these simulations are shown in Fig. 1.

In Fig. 1, the costs and savings due to the alternative CCTV schemes are shown by red squares with the original best estimate highlighted by blue shading. The improved street lighting variations are shown by yellow circles with the original best estimate highlighted in pink. There are less than 128 points for the lighting alternatives because some combinations of parameters give the same result.

5. Discussion

The Monte Carlo simulations provide an indication of the conditions needed for a CCTV scheme to approximate the cost benefit performance of an improved street lighting scheme. Only in the most optimistic combinations of these parameters would CCTV achieve this. In addition, we have already chosen more favourable conditions for CCTV schemes by selecting only those in the UK. A major factor in this is that upgrading the existing street lighting is much cheaper than the initial installation that is usually necessary for CCTV. This is not the only reason for the difference however. The effect of improved street lighting on violent crime, at 9.09% is more than three times that of CCTV at 2.91%. Also, since violent offences (including robbery and sexual offences) make up about half the total cost of street crime, improved street lighting has more opportunity to have an effect. Meanwhile, vehicle theft is the only large category where CCTV, at 25.93%, scores best. There is much less scope for crime reduction here. However, CCTV may be more effective in areas where vehicle crime predominates.

The results also compared a range of strategies for implementing CCTV and lighting schemes. This indicated that targeting crime hotspots was easily the most effective strategy for both CCTV and lighting schemes so that both approaches are likely to be most efficient in small, highly targeted schemes. However, the larger lighting schemes were also cost efficient to some extent. We found that hotspots, which are defined as postcodes with numerically the highest levels of crime, were easily identifiable from past crime data and were often persistent for several years. Hence, this would be a feasible strategy in practice.

As noted earlier, whether CCTV is actually effective at reducing crime or not, is disputed. This research shows that even if it is effective, there are few situations where it is more effective in financial terms than improved street lighting as a means of deterring crime. Apart from crime prevention, Isnard (2001) gave several other goals for surveillance camera systems such as reducing the fear of crime. Other reasons for installing CCTV is in efficiently directing police resources to improve the detection of crime and so obtain a consequent reduction in the cost of the police investigation and court proceedings. However, based on Dubourg, Hamed and Thorns (2005: 12), costs to the criminal justice system make up only 20% of the cost of crime. Of this, using figures from Table 2.1, costs to the prison service make up 70% of these and would still presumably be incurred when the offender is caught. This means that easier detection and conviction only target 6% (the remaining 30% of 20%) of the cost of crime. It is difficult to see how this additional saving could reverse the large differences in the effectiveness of CCTV compared to improved street lighting found here. Nevertheless, these are the principal justifications made to the public for the funding and use of open street CCTV. If there are other reasons for the widespread deployment of CCTV then they should be made explicit and justification based on these.

There seems to be no data available on what would happen if street lighting is dimmed. Such an experiment may even be deemed unethical because, considering the results above, the unwitting participants may be exposed to an increased risk of being a victim of crime. However, this experiment is being carried out now, as apparently to save money, councils reduce the brightness of lighting and have them switched on for fewer hours. In some cases, lighting is reduced or turned off after midnight. This is a particular concern because we found that in Glasgow, the rate of violent street crime was at its maximum between 12 and 1 am. Early results have not detected any increase in crime due to this type of scheme (Steinbach et al., 2015) but there can be no guarantee that this will continue to be the case.

Two issues that have not been modelled are the possibilities of the dispersion of crime into other areas and the diffusion of the benefits of crime reduction. While both effects may be in operation, it was not clear from the available literature which was more prevalent. Since they act in opposite directions, they must cancel out to some extent and the combined effect has been assumed to be negligible here. If a meta-analysis was conducted that gave clear indications of the type of situation in which each effect dominates, the cellular automaton format would be well suited to modelling the results because it contains the spatial information of postcodes and their neighbouring cells. There is also potential for further work in disaggregating the results by offence location such as: car parks, footpaths, roads etc., which would improve the resolution of modelling the effects of crime interventions in different locations. The scope of the model here is restricted to CCTV and street lighting. These were chosen largely because the meta-analyses of Welsh and Farrington (2008a, 2008b) provide the data needed for modelling. Also, these two measures are often used by agencies such as local authorities, so a decision support tool is particularly relevant in this area.

Although the cost of improved street lighting is low relative to the potential benefits, there is still a considerable initial cost. This is usually borne by the local authority. However, it is mainly other institutions that enjoy the cost savings of reduced crime such as the health services, the police, probation, the courts, the prison service, as well as the victims themselves. In this context, there is limited incentive for local authorities to make the necessary investment and it would seem more appropriate that funding for any street lighting improvement schemes to reduce crime be funded by central government.

These results were obtained in Glasgow but the cellular automaton could be adapted for use in optimising crime prevention measures at other locations. This would involve changing the input data file for local crime rates, CCTV and lighting parameters. However, since the marginal change in crime that occurs in response an intervention and the cost of crime are based on national data, the model would be equally applicable to other UK cities.

6. Conclusions

While there is still considerable uncertainty around the effects of CCTV and improved street lighting as crime prevention measures, the Monte Carlo modelling described here adds to the debate on the cost effectiveness of these technologies, provides general guidelines for efficiently implementing crime reduction schemes and presents a modelling tool with the potential for assisting with the design of interventions.

Previous literature has tended to focus on the extent to which either CCTV or improved street lighting is effective at reducing crime. This paper moves the debate on, by considering effectiveness in a cost benefit framework, staging a head-to-head comparison between the two approaches. The main conclusion is that there are few situations where CCTV is more cost effective than improved street lighting for preventing crime – provided it can be based upon existing lighting infrastructure. There is no longer a case for the widespread use for CCTV surveillance on the grounds of crime prevention alone. The secondary result is that the maximum benefit per unit cost can be obtained from intervening in the highest crime location first, then working into successively lower crime locations.

The model is based on the average effect on crime of the schemes reported in Welsh and Farrington (2008a, 2008b). In practice, the effect of a real crime reduction scheme is contingent on many factors that are not included in our model so that its effects can be expected to be distributed around this prediction – there is no guarantee that a particular scheme will perform as expected or that the effectiveness of CCTV and lighting will continue be behave as they have in the past. Nevertheless, we believe that basing policy on the best available research presents the greatest opportunity for reducing crime in a cost effective way.

Acknowledgments

This research was funded by the UK Economic and Social Research Council (ESRC) Grant Number: ESRC - ES/L003287/1.

References

Cohen, L., & Felson, M. (1979). Social change and crime rate trends: A routine activity approach. *American Sociological Review, 44*, 588–608.
Commission for Dark Skies (2015). http://www.britastro.org/dark-skies/index.php.
Community Safety Glasgow (2015). CCTV Location for Community Safety Glasgow. https://data.glasgow.gov.uk/dataset/cctv-location-for-community-safety-glasgow.
Cozens, P., & Love, T. (2015). A review and current status of crime prevention design (CPTED). *Journal of Planning Literature, 30*(4), 393–412 November 2015.
Davies, S. (1997). *10 reasons why public CCTV schemes are bad.* Privacy International. 28/4/97 http://www.1in12.com/publications/cctv/tenreasons.html.
Dee, M. (2000). *The Use Of CCTV To Police Young People In Public Spaces - A Case Of Big Brother Or Big Friend? Paper presented at the 27th International Conference on Making Cities Livable, Vienna, Austria.* Leicester, LE7 9SU, U.K.: De Montfrot University, Youth and Community Division, Scraptoft Campus.
Ditton, J. (1999). *The effect of Closed Circuit Television on recorded crime rates and public concern about crime rates in Glasgow.* Scottish Office/HMSO.
Dubourg, R., Hamed, J., & Thorns, J. (2005). The economic and social costs of crime against individuals and households 2003/04. *Home office online report 30/05* (June 2005).
Eck, J. E., Clarke, R. V., & Guerette, R. T. (2007). Risky facilities: Crime concentration in homogenous sets of establishments and facilities. *Crime Prevention Studies, 21*(2007), 225–264.
Gilbert, N., & Troitzsch, K. (2005). *Simulation for the social scientist – Second edition.* England: Open University Press.
Gill, M., & Spriggs, A. (2005). *Assessing the impact of CCTV, home office research study 292.* Home Office Research, Development and Statistics Directorate (February 2005).
HMIC (2014). Crime recording – Making the victim count. *The final report of an inspection of crime data integrity in police forces in England and Wales*HMIC (November 2014, ISBN: 978-1-78246-660-4).
Home Office (2011). Revisions made to the multipliers and unit costs of crime used in the integrated Offender Management Value for Money Toolkit. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/97813/IOM-phase2-costs-multipliers.pdf.
Hood, J. (2003) {published and unpublished data} in Welsh and Farrington (2008a) Effects of closed circuit television surveillance on crime, Campbell Syst. Rev., 2008:17, December 2008.
Isnard, A. (2001). Can surveillance cameras be successful in preventing crime and controlling anti-social behaviours? *Paper presented at The Character, Impact and Prevention of Crime in Regional Australia Conference*Townsville: Australian Institute of Criminology (2–3 August 2001).
ONS (2012) Table 1.06, Percentage of CSEW incidents reported to the police, 1981 to 2011/12 CSEW2 with statistical significance of change between 2010/11 and 2011/12, appendixtables_tcm77-299150-1.
Painter, K. A., & Farrington, D. P. (1997). The crime reducing effect of improved street lighting: The Dudley project. In R. V. Clarke (Ed.). *Situational crime prevention: Successful case studies* (pp. 209–226). (2nd ed.). Guilderland: Harrow and Heston.
Painter, K. A., & Farrington, D. P. (1999). Street lighting and crime: Diffusion of benefits in the Stoke-on-Trent project. In K. A. Painter, & N. Tilley (Vol. Eds.), *Surveillance of public space: CCTV, street lighting and crime prevention. Crime prevention studies. 10. Surveillance of public space: CCTV, street lighting and crime prevention. Crime prevention studies* (pp. 77–122). Monsey: Criminal Justice Press.
Pease, K. (1999). A review of street lighting evaluations: Crime reduction effects. In K. A. Painter, & N. Tilley (Vol. Eds.), *Crime prevention studies: . Vol. 10. Surveillance of public space: CCTV, street lighting and crime prevention* (pp. 47–76). Monsey, NY: Criminal Justice Press.
Scottish Futures Trust (2013). Street lighting toolkit. February 2013 https://www.scottishfuturestrust.org.uk/files/publications/Street_Lighting_Toolkit.pdf.
Scottish Futures Trust (2016, August 31). Scotland's street lighting energy efficiency programme. http://apse.org.uk/apse/assets/File/SFT%20Presentation%2031st%20August%202016.pdf.
Smith, K., Taylor, P., & Elkin, M. (2013). *Crimes detected in England and Wales 2012/13* (second ed.). *Home office statistical bulletin 02/13*Home Office (July 2013, ISSN 1759 7005).
Steinbach, R., Perkins, C., Tompson, L., Johnson, S., Armstrong, B., Green, J., ... Edwards, P. (2015). The effect of reduced street lighting on road casualties and crime in England and Wales: Controlled interrupted time series analysis. *Journal of Epidemiology and Community Health, 69*, 1118–1124 2015. (doi: 10.1136).
Tien, J. M., O'Donnell, V. F., Barnett, A., & Mirchandani, P. B. (1979). *Street lighting projects: National Evaluation Program, phase 1 report.* Washington, DC: National Institute of Law Enforcement and Criminal Justice, U.S. Department of Justice1979.
Welsh, B. C., & Farrington, D. P. (2008a). Effects of closed circuit television surveillance on crime. *Campbell Systematic Reviews, 17* (December 2008).
Welsh, B. C., & Farrington, D. P. (2008b). Effects of improved street lighting on crime. *Campbell Systematic Reviews, 13* (September 2008).
Welsh, B. C., Farrington, D. P., & Gowar, B. R. (2015). Benefit-cost analysis of crime prevention programs. *Journal of Crime and Justice, 44*(1), 447–516.
Woodhouse, J. (2010). *CCTV and its effectiveness in tackling crime.* Standard Note SN/HA/5624. House of Commons Library (1 July 2010).