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Engineering

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This chapter examines the contribution of engineering sciences to crime reduction. Beginning with a conceptual discussion about what engineering is, the chapter then uses the concept of system to draw links between engineering and crime reduction. It points to the fact that contemporary systems cannot be neatly divided between purely physical and purely social systems, and that many systems relevant to crime (e.g. criminal justice system, surveillance and monitoring systems, urban ecosystems, etc.) are made of people, built structures, technological devices and information. Consequently, the chapter argues that a significant part of crime science – that concerned with the development and management of security systems or less criminogenic systems – is a form of (security) engineering, and that better understanding the points of interaction between engineering and criminology is a necessary step to advance crime science's scholarship.

1. Introduction

Technology can support security. This argument is neither novel nor the object of intense debates. It is well known that advances in military warfare, for example, were often decisive in conflicts between nations. The link between crime analysis and engineering, however, seems a lot more tenuous, and collaboration between criminologists and engineers is relatively seldom. That is not to say that engineering has little to offer to crime prevention and counter-terrorism, nor that it does not intersect with the scholarship of social scientists. This chapter will argue quite the opposite. The absence of a clearly delineated academic agenda shared by both communities is therefore somewhat perplexing.

The connection between crime science and engineering has only been sporadically discussed, and often reduced to the development of security technology (Davis & Pease, 2001; Kemp et al., 2003; Metke & Ekl, 2010; Qadri & Asif, 2009; Savona, 2004). It can be argued though that engineering has a broader influence on crime (Junger, Laycock, Hartel, & Ratcliffe, 2012) and perhaps that crime science might have influenced engineering. Focusing on the first point, this article examines and discusses the impact the engineering community has (or could have) on crime-related harm in society.

For our purpose, it is important to appreciate that those effects can come from at least two different sources: the contribution of research engineers to knowledge and the work of practising engineers in society. In addition, to err is human. Crime-related harm is therefore not limited to the harm caused by criminal activities but also includes the unintended harm caused by inadequate crime-reduction activities (Borrion et al., 2012, Grabosky, 1996, Norrie, 2002). With this in mind, we can refine the scope of this inquiry to the following question: how can the knowledge developed in engineering and the work of practising engineers influence the harm caused by criminal offences and crime-reduction interventions?

2. Engineering in the 21st century

Before getting to the heart of the matter, this section touches upon the fundamental issue of what engineering is. The intent is to show that oil-smeared mechanics and Victorian pioneers are as good as illustrations of 21st-century engineering as Miss Marple is of predictive policing.

The field of engineering (eng.) contains many different areas including aerospace eng., chemical eng., civil eng., electrical eng. environmental eng., medical eng., mechanical eng., and systems eng., which makes it notoriously difficult to define. The Merriam-Webster dictionary for students, for example, refers to it as ‘the application of science to the goal of creating useful machines (such as automobiles) or structures (such as roads and dams)’. In the regular edition, the definition is broadened to encompass the management (not just creation) of any useful systems (beyond just physical ones): ‘the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people’. This more inclusive definition is interesting for it includes scientific areas that do not revolve around machines or structures, such as bio-engineering – ‘the application of biological techniques (such as genetic recombination) to create modified versions of organisms’ (ibid.). Even more inclusive is the following definition which focuses solely on the intended outcome, with no restriction about the type of systems concerned or the disciplines from which the techniques involved in their development originate: ‘the control or direction of something (such as behaviour)’ (ibid.).

In the absence of an official definition, the term engineering continues to be construed in different ways by different communities, including the engineering community itself. For our benefit, we shall avoid any dogmatic discussion and concentrate on the most distinctive and consensual characteristics:

Lifecycle management of systems to meet specific needs

Engineering is not just – or no longer just – about building physical things. Its purpose is the lifecycle management of systems to meet specific needs (INCOSE, 2015). In this context these terms refer to the different stages (from cradle to grave) of artificial products ranging from genetically modified bacteria to the International Space Station or the internet.

The engineering philosophy is that every decision in a product's life should be strictly based on one driver: the fulfilment of specific requirements that represent the needs of the relevant parties. This relation to problem-solving – defined as 'any goal-directed sequence of cognitive operations' (Anderson, 1980, p. 257) – is also what distinguishes engineering design from artistic design.

Greater capability under greater constraints

In most people's minds, it seems that technological innovation equates to greater capability in the service (or disservice) of the population. In the media, technology headlines tend to be about the impressive features of a new smartphone or a new world record (e.g. fastest communication link, tallest building, longest bridge, largest plane, etc.). Less glamourous but more representative of everyday engineering practice is the ability to meet ever more stringent demands. For example, changing commercial and regulatory pressures created the need for engineers to design cars that are more affordable and have a reduced carbon footprint, without sacrificing performance or comfort.

Research and practice in engineering

As with other applied fields, novel engineering knowledge is generated through research activities and subsequently applied by practitioners to achieve specific outcomes in society. For various reasons, the engineering community is not neatly divided between research engineers and practising ones but instead is distributed across a wide spectrum, with many jobbing engineers carrying out research and development activities in industry and university researchers also developing close-to-market innovations.

Scholarship

A significant part of engineering scholarship concerns the ways in which requirements can be elicited and then how the resources available around us can be harnessed to ensure that man-made systems satisfy those requirements. Contributing to this overall aim, engineering activity typically draws on the more fundamental sciences to create application-focused knowledge:

- On the theoretical side of the spectrum is the scientific research conducted to characterise existing phenomena and understand 'how they work'. There, the inquiry process is generally conceptualised around specific explanatory hypotheses of cause-and-effect relationships. As an example, knowledge is continuously gained to better model and analyse electromagnetic fields because of their application to wireless communication technology in general.

- On the more applied side of the spectrum are actual engineering projects. In those, the knowledge available in various disciplines is combined to satisfy the needs of specific stakeholders (such as contractors, regulators and users). The development of a fully operational wireless detection system for an indoor environment would require knowledge of physics and electronics but also other disciplines to ensure that the final product satisfies the operational, legal, ethical, environmental and commercial constraints that exist in the real world.

- Engineering research tends to lie somewhere between the two. It aims to identify how scientific knowledge can be exploited to support a range of applications. In a typical project, researchers would propose a technical innovation (e.g. a method to detect and localise moving targets by analysing ambient Wi-Fi signals) and demonstrate that it has certain properties likely to be sought after in industry. That a given element in its design confers on it those properties is the so-called research hypothesis – though it is rare for engineers to present it as such.

The distinction between research and practice can perhaps explain the lack of collaboration between criminologists and engineers at university. Like other scholars, research engineers focus on producing original knowledge in their field. To this aim, the development of a complete and operational system that can directly or indirectly help reduce crime (e.g. a system to detect illegal logging) would often prove too time- and resource-intensive. Development and evaluation of a communication protocol or a prototype sub-system (e.g. a component in the electronic circuit of such a system) is generally sufficient to demonstrate progress beyond the current state of the art. A lot more work would usually need to take place before an operational system can be manufactured that could be used in the field, and while the overall system (and the environment) might be outlined, research engineers (as opposed to practising engineers) would normally put as little effort as possible into this since this is not the focus of the work.

In crime science, however, evaluating an intervention often requires working on complete systems in their actual contexts of implementation as people's behaviour can be very sensitive to situational conditions (Lewin, 1936). A scientific criminological evaluation of alley gating such as that conducted by Bowers, Johnson, and Hirschfield (2004) requires data about the occurrence of burglary in real (gated and ungated) alleys, as many ecological factors would be impossible to replicate with high fidelity in a laboratory setting.

In spite of this, there are many reasons why anyone embracing the outcome-focused approach promoted in crime science ought to take an interest in engineering scholarship:

1. Systems engineering – 'an interdisciplinary approach and means to enable the realization of successful systems' (INCOSE, 2015) – can offer valuable processes, techniques and principles to manage the lifecycle of crime-reduction measures including new policies and procedures.
2. Analysts and designers may need to call upon engineering knowledge whenever human-made systems are relevant to the stages of those processes. In particular, they may need it:

- To analyse the products and services created by engineers in order to assess how they might affect crime and reduce their criminogenic characteristics
- To create security systems for the purpose of detecting crime, preventing it or reducing the harm it causes.

3. System: an interdisciplinary concept

3.1. Origins

The terms 'system' and 'systems thinking' are both so fundamental to engineering sciences that appreciating the relevance of engineering to crime science requires some understanding of them. For this reason, we shall start with an overview of those concepts. For a more comprehensive introduction, the reader is encouraged to read the system engineering handbook by INCOSE (2015):

- A system is an integrated set of elements including products, processes, people, techniques, facilities, services and other support elements.
- The surroundings in which the system of interest is developed, produced, used and retired is called the environment.
- A system is often characterised through the description of its boundary, structure, behaviour and function, adopting both internal and external views.

Systems thinking can be traced back to Aristotle's time, when he described a hierarchic order in nature. In more recent times, it has been linked to the concept of holism, introduced by Smuts (1926) as an alternative to the reductionist approach. Holism promotes the idea that systems cannot be fully understood by considering them as collections of parts. In the same vein, the most emblematic tenet of systems theory – 'the whole is greater than the sum of the parts' – was articulated by Wertheimer (1938), a contributor to Gestalt psychology.

An application of systems theory referred to as the systems approach considers that all aspects of human problems should be addressed together in a rational manner. In essence, this approach advocates that attempts to meet a specific need should be done in a top-down manner, considering the impact of interventions on other needs too. For example, first-generation biofuel was initially proposed as a solution to reduce the ecological and health impacts of motor vehicles. According to the systems approach, this is not a proper solution because its production would stimulate major changes to land use that would affect food security in different parts of the world (Rulli et al., 2016).

Clayton & Radcliffe (1996, p. 18) write that the 'systems approach involves placing as much emphasis on identifying and describing the connection between objects and events as on identifying and describing the objects and events themselves'. This is particularly important with so-called open systems (i.e. systems that both affect and are affected by their environment). Summarising the work of scholars such as Ludvig von Bertalanffy (1950) and Joseph Litterer (1969), Skyttner (2005, p. 53) explains that 'there is near total agreement on which properties together comprise a general theory of open systems: Interrelationship and interdependence of objects and their attributes, Holism, Goal seeking, Transformation process, Inputs and outputs, Entropy, Regulation, Hierarchy, Differentiation, Equifinality and multifinality'.

Drawing on those elements, the first systems engineering methods were developed by NASA to help engineers deal with the complexity of space projects in the 1960s (ibid., p. 472). Forty years later, those methods and their terminology continue to unify the various domains of engineering.

3.2. Systems thinking

Within engineering, adoption of a systems-thinking approach is recommended to design, retrofit or reverse-engineer products and infrastructures. Taking a wind-energy system as an example, an engineer would aim to reach the point where they understand how the design parameters of the system influence the supply of electricity in people's homes. Based on their knowledge of the system and its environment, engineers would then try to model its behaviour under different conditions, assess the various risks of failure over time, and ultimately validate or improve it.

It is by identifying, understanding and controlling the interactions that are involved in the process supported by the system that the sought output is eventually secured. This task typically involves creating an inventory of all contributing elements; defining the boundaries of the different subsystems; and developing a range of physical, operational and logical models for every element within those subsystems (such as the turbine's rotor blades, shaft, nacelle, gearbox, generator, cables, and power substation) and for the interactions between them (e.g. the wind applies a force on the blades which makes the drive shaft spins, etc.).

Because their development, deployment and operation phases are not conducted in a vacuum, systems must be analysed in relation to other systems in their environment. In the above example, a systems-thinking approach would lead engineers to understand what influence external events can have on the constituents of the system and the system as a whole. They might use agent-based models to simulate wind power integration with a smart grid, and understand how demand response might mitigate the impact of wind power variability (Brooer et al., 2014). In principle, they would also assess the negative effects of, say, wind turbines on other human activities such as air traffic control (Nicholls & Racey, 2007) and on wildlife (Lemmon, Carroll, Sanders, & Turner, 2008).

Systems thinking is routinely applied to manage systems across industrial sectors (e.g. defence, energy and transport) in order to build enhanced capability or tackle problematic phenomena. It is, for example, used to create physical and cyber-security systems (e.g. Evans et al., 2004; Lee, 2008) and reduce the environmental impact of industrial activities and citizens' actions in society (e.g. Seiffert & Loch, 2005). Although generic systems engineering frameworks exist, their contextualisation to crime has been mostly limited to the area of information security and cyber-security.

3.3. Systems and crime

There are noticeable differences between engineering and crime science (see Table 11.1). To date, crime-science research has been mainly focused on crime reduction (with only a few articles evaluating the wider effects of interventions), the analysis of crime phenomena (rather than the development of interventions to prevent them), and the factors influencing offenders' decisions to commit crime (rather than the impact of offenders' actions on people, infrastructures and electronic systems). Despite this, engineers and crime scientists share the core objective of solving problems in an effective and ethical way, and the differences summarised in Table 11.1 are perhaps more due to the fact that crime science is still in its infancy and crime-science research remains dominated by the work of researchers trained in criminology, psychology and geography.

Table 11.1

Characteristics of engineering and crime science

	Engineering	Crime science*
Aim	Satisfaction of the stakeholders' needs	Reduction of crime, increases in security
Unit of analysis	Multiple units (including high-level ones) based on the stakeholders' requirements	The crime event
Type of work process	Multi-criteria systems engineering frameworks	Crime-centric problem-solving models (e.g. SARA)
Main stages	–Eliciting stakeholder requirements –Specifying every aspect of a system's lifecycle and managing it to satisfy stakeholder needs	–Identifying crime patterns –Analysing their causes –Identifying and implementing interventions to disrupt causes –Evaluating effectiveness of interventions
Researchers' bias	Toward system development	Toward problem analysis

Note: *These are dominant characteristics observed in the literature

Pragmatically and intellectually, the proposition that crime science is a field analogous to medicine (Laycock, 2005) is very attractive. To support this interdisciplinary vision, the crime-science community will need to acknowledge that the field goes beyond environmental criminology. It will also need to identify how other research areas (in architecture, biology, chemistry, computer science, economics, physics, etc.) relate to criminological theories and where they fit in the 'big picture' of crime reduction (Borrion & Koch, 2017). Owing to its broad scope, systems engineering can offer a unifying framework for this task.

Integrating crime science with engineering is challenging in practice. If it does happen in the future, it is likely to be around the concept of systems. The main reason is that many of the principles and techniques found in crime science are related to problem-solving and systems theory:

- Problem-Oriented Policing (POP) is a goal-based approach inspired from Operations Research and similar to that followed in engineering (Goldstein, 1979; Wilkins, 1996).
- Problem-solving models such as Scanning-Analysis-Response-Assessment were derived from systems theory (Eck & Spelman, 1987).
- Environmental criminology is based on the fundamental distinction between individuals and their environment, and the recognition that, as open systems, both exert causal influences on the other (Clarke & Eck, 2005; Wortley & Mazerolle, 2013).
- The components of systems analysis are also found in Routine Activity Theory where occurrence of crime events is said to be influenced by people's routine activities (Cohen & Felson, 1979), and can thus be regarded as an emerging property of the ecosystem.
- Realistic evaluation is also closely linked to systems thinking theory in that it argues that evaluators should seek to understand the causal mechanisms (i.e. cause-and-effect interactions) that are responsible for the occurrence of outcome patterns (including crime events), as well as those that prevent them (Pawson & Tilley, 1997).

4. When engineering matters

4.1 The concept of causal chains of events

In crime science, systems thinking is perhaps most evident in the implementation of agent-based models. With those, offenders' behaviour is represented as a function of their inherent disposition to commit certain actions and the influence of the environment on their motivation (Malleson et al., 2013). For this reason, those developing agent-based models of crime must make a conscious effort to identify the main situational elements that impact on offenders' intent, motivation and capability (c.f. Hill et al., 2014; Le Sage et al., 2013; Thornton, 2015).

Analogous to the previous example about wind energy, controlling crime requires understanding how exposure to and interactions with other systems affect human behaviour. With this information, it is then possible to hypothesise specific chains of events that could modify the conditions that give rise to crime, and identify the properties a system should have so as to effectively trigger or enable such properties to happen. This point is illustrated in Example 1.

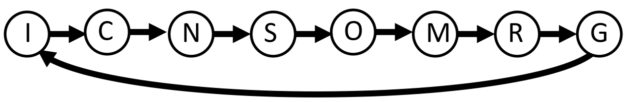
Example 1: CCTV security process

In many countries, Closed-Circuit TeleVision (CCTV) is deployed in public and private spaces to address crime problems. In many people's minds the security measure is the camera; in practice though, it is only a part in a larger system, and would have a limited impact on its own. Tilley (1993) identified several ways in which CCTV cameras might plausibly affect crime. To deter offenders, it must make offenders 'perceive an elevated risk of apprehension'. This presupposes that offenders notice the camera and that they have developed certain schemas about CCTV and the risk of being caught. Depending on the way it is implemented, a camera may or may not deter an offender. Similarly, the deterrent effect of a camera probably depends on the experience an offender previously had with CCTV cameras.

To interdict offenders, a camera is used as part of a security process. As represented in Figure 11.1, an Individual's image is first captured by a Camera, transmitted over the Network, rendered on a Screen and analysed by an Operator. Based on the information provided by the latter, the security Manager will then use their Radio and task a security Guard to physically intervene against the Individual. Each component of the chain is identified by its initial in the figure (I for Individual, C for CCTV, etc.). To understand the requirements that CCTV-based security systems must meet, it is critical to be able to model the various stages of the process, and identify the factors that may affect those.

Figure 11.1

Interactions between the various elements of the CCTV security process



4.2 Wider impacts of crime-reduction measures

Introducing crime-control measures presents many challenges. In the case of Situational Crime Prevention in particular, modifying an environment often causes changes in the behaviour of people and physical systems, which means the impacts of security technologies should be monitored very closely. Designers must therefore consider a very large number of potential chains of events to ensure that they meet the stakeholders' wider needs (in terms of their implementation cost but also ethical and environmental impacts).

In socio-technical systems, many of the interactions that contribute to those events involve people. This is why contemporary engineering cannot be limited to the physical sciences but also draws upon expertise from the cognitive and behavioural sciences for the lifecycle management of systems (e.g. Tripathi & Borrion 2015). Evidence of this can be found in the existence of academic communities specialising in the areas of human-machine interface, systems ergonomics, human errors and safety issues. The importance of human factors in security engineering is further discussed through the case of airport security scanners in Example 2.

Example 2: airport security

Since 9/11, significant changes have been made to airport security checkpoints across the world (Blalock et al., 2007). In this example, we examine some of the dependencies that exist between a luggage scanner and the entities that surround it. The manifestation of the properties of the scanner (e.g. what is displayed on the screen), for instance, depends upon the supply of electricity from another system (e.g. the power distribution network), the way the scanner is operated, and the inputs it receives (e.g. the bags to be scanned). It also depends upon the occurrence of external events that would affect its performance (e.g. high temperature). The scanner may be affected by sabotage attempts too.

The relevance of human factors is most obvious when examining the effect of the scanner on its environment. As soon as it is deployed, the device impresses upon passengers that security is a serious business. It changes the spatial properties of the security checkpoint, influences the speed, trajectory, actions and mood of individual passengers, and affects the security guards' field of view and movements. Depending on the situation, the scanner can also cause different responses from the guards (such as questioning passengers or searching their bags), including unethical ones. Deterrence is only one of many different impacts that a scanner can have on people, and focusing exclusively on it would be regarded as very poor engineering practice.

4.3 From behavioural requirements to system requirements

Overlooking some of the stakeholders' needs is very common in engineering projects. This may happen when those needs are not (or not properly) articulated in the first instance or when designers focus too much on the functional aspects of those systems. However, too narrow an approach could result in the creation of interventions with unacceptable side effects. To ensure that they produce the sought-after outcomes and foster the expected behaviours, designers of crime-reduction interventions must likewise understand what constraints prevention measures should meet. They must also develop a thorough understanding of the interactions that are relevant to those needs, both within and between systems (Blanchard et al., 2007). In practice, however, it can be difficult for experts to translate requirements about human behaviour into technological requirements, as shown in Example 3.

Example 3: CCTV failures

Many of the failures associated with control measures are not due to technological defects but poor specifications (van Lamsweerde, 2009). As an example, I was made privy to an anecdote concerning an electric gate that was repeatedly damaged in a private residence. To deal with the problem, one of the residents had suggested that, on future occasions, the management company should use the CCTV camera monitoring the gate to identify the culprits. The answer he received was that this was logistically impossible because, by the time the company processed the request, the standard 30-day data retention period would have expired and the CCTV footage would have been erased!

A list of similar issues that can influence the effectiveness of CCTV-based security processes are presented as an example below (Table 11.2). It is noticeable that many of them would typically occur if technologists were to overlook behavioural requirements or if behavioural analysts were unable to translate them into technological requirements

Table 11.2

List of CCTV systems failures

Type of issue	Example
Implementation	Introducing a camera as a deterrent but not making it sufficiently visible
Implementation	Orienting a camera toward a wall or setting it up in a location where it is regularly obstructed by lorries
Quality	Having an image resolution so low that the retrieved information is not actionable; performing poor or no maintenance
Capacity/usability	Deploying more camera feeds than can be monitored by CCTV operators
Capacity	Lacking CCTV personnel who could detect threats or act upon them
Integrity	Lacking a suitable process to manage the chain of evidence for forensic use
Interoperability	Recording video data in a format that cannot be retrieved by police investigators
Acceptability	Misusing CCTV equipment resulting in loss of public confidence or distrust (e.g. making CCTV feeds accessible to unauthorised parties; using it for an illegitimate purpose)
Security	Deploying CCTV equipment in locations where offenders can easily destroy them

4.4 Interactions with/within engineered systems

So far we have highlighted that designers must consider the interactions between systems that could affect crime reduction and other stakeholder needs. Because crime events take place in real-world environments, those interactions may happen not just between people, but also between people and human-made systems; or even between human-made systems only. It seems that the main reason for taking an interdisciplinary approach in crime science lies in this diversity.

Understanding what influences people's motivation and behaviour is the bread and butter of scholars in the cognitive and behavioural disciplines. However, this expertise alone is not sufficient to tackle the numerous research challenges that exist in crime science:

- Not every aspect of the causal chains of interest is about people's motivation or self-control. For instance, a different type of expertise is needed to propose a method that can determine whether the cause of, say, a child's bone fracture is really accidental (osteology and mechanical engineering); to propose and assess tactics against drone-borne explosive devices (mechanical and electronic engineering); or to assess how many computers are likely to be infected by a given type of malware (computer science).

- Where interactions are concerned with human behaviour, they may also be influenced by a number of factors that are best understood with some knowledge of engineering. For example, people's intent and motivation to carry out an action depend on their awareness of the opportunity (i.e. that the action is an option and that it would support their goals), and their perceived capability to carry it out successfully. When those actions directly concern a technological system (e.g. computer or weapon), in-depth analysis cannot always be done without a minimum understanding of the technology.

For years, crime scientists have been studying crimes such as theft and physical violence. Their choice can be explained by the prevalence of those types of crime in society and their desire to achieve impact. We can also note that most social scientists would be familiar with the type of environments in which those crimes occur, and could rapidly come to terms with the rather unsophisticated modus operandi used by criminals.

In contrast, contextualising crime-science principles to problems involving more complex targets, advanced weapons, sophisticated modus operandi, high-tech control measures or unusual environments is not as straightforward. For instance, not every crime scientist has the domain knowledge needed to carry out research on money laundering involving Asian arts and antiques in the 19th century.

For the same reason, engineering knowledge may be required whenever the emerging properties of an ecosystem are based on human-made systems. In many cases, adopting a black-box approach whereby systems are only described in terms of inputs, outputs and the relation between those, without looking at what happens 'inside' them, is an option. However, this presupposes that sufficient information is available about the behaviour of the studied systems under a wide range of external conditions. In practice, this is rarely possible for socio-technical systems and a more interdisciplinary approach must be adopted.

Without some overlap in their knowledge base, it would be difficult for a crime expert and an engineer to collaborate effectively. Crime experts cannot be expected to ask pertinent questions about a system if they do not know anything about it; and engineers cannot guess what information crime experts might need to know about a system if they have no understanding of behavioural and crime-prevention principles. This is also why greater integration between these domains is needed.

5. Conclusion

University researchers can usually select the problems they wish to study. Most criminologists and crime scientists are free to cast their eyes only on problems that can be analysed without understanding a great deal about technology. They can restrict their creativity to propose only interventions that can be identified without engineering knowledge. They can also decide to evaluate only crime-reduction measures that do not interact with engineered systems. Academic journals are home to millions of articles written by experts who have found a niche where they can enjoy the reassurance of a monodisciplinary life. Nevertheless, the increasing presence of technology (such as autonomous systems, crypto-currency, internet-enabled services or smart cities) in society calls for a new breed of experts capable of engineering crime out while minimising the negative consequences of interventions. If, like an intrepid hobbit, you think you might be ready for an adventure, this article will have hopefully helped you see untapped opportunities in crime science.

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