Developing Mathematical Models of Complex Social Processes: Radicalisation and Criminality Development

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I, Rosemary Claire Pepys, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work.

Abstract

The purpose of this thesis is to examine the use to which mathematical modelling techniques can be put in answering hard questions in social science. The specific area that this thesis focuses on is the development of an individual's propensity for crime or terrorism, with the primary research question answered being: are the process by which an individual develops the propensity to commit crime and the radicalisation process indistinguishable? The answer to this question may assist policy makers and practitioners in the fields of counter-terrorism and crime prevention develop more effective interventions, but it is a difficult question to answer using techniques rooted in social science alone, as crime and terrorism are the outcomes of complex social processes that form part of large socio-ecological systems.

The thesis answers this question through the use of mathematical modelling. A model is developed based on the Individual Vulnerability, Exposure and Emergence (IVEE) theoretical framework for radicalisation. This model is realised as a computer simulation imitating the process by which an individual develops the propensity to commit an act of crime or terrorism, and is parameterised using data from secondary sources. The behaviour of the simulation is then explored to determine whether, with sufficient data, it could potentially be of practical use to practitioners: for example, the simulation is used to explore whether crime prevention interventions might also be effective for countering radicalisation, or vice versa.

It is concluded that while the simulations developed in this thesis are still theoretical, the models themselves have the potential for further development, and the methodology could be applied to a range of alternative fields.

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Chapter 1

Introduction

Mathematical modelling has played a key role in the advancement of human knowledge and civilisation throughout history. Without the heliocentric model constructed by Nicolaus Copernicus the human race might have continued believing the earth to be at the centre of the universe for many centuries, while models based on Isaac Newton's laws of motion were an essential precursor to the industrial revolution. More recently, mathematical models have been used for a range of purposes across many disciplines, and have been essential for advancing fields as varied as aeronautical engineering (for example, by establishing the most aerodynamic shape for aircraft wings or turbine blades), meteorology (such as providing early warnings prior to extreme weather events) and economics (to predict the impact of changes in fiscal or monetary policy). And yet despite the proven record of mathematical modelling across so many fields, its use as an aid to social scientists remains to be substantiated.

The purpose of this thesis is to develop mathematical models that could be of practical use to practitioners in the fields of crime prevention and counter-radicalisation. Radicalisation in particular is an area that has been of increasing interest to academics and policy-makers since the events of 11^{th} September 2001. However the process by which people become radicalised has long been acknowledged by experts in the field as being incredibly complex: people who have become radicalised have originated from a range of ethnicities, religious groups, nationalities, and socio-economic backgrounds. A similar argument can be made for those who choose to commit acts of crime: while there may be correlations between some offenders' backgrounds and the types of crimes they choose to commit, these correlations do not amount to causal factors explaining why people develop the propensity to commit crime in the first place. The processes by which people develop such a propensity are complex, but it is only by truly understanding the causal mechanisms in these processes that policies can be put in place to effectively reduce the likelihood that people develop the propensity to commit crime or acts of terrorism. It is for this reason that the author hopes that by taking the approach of using mathematical modelling to further understanding of these processes, the use of this methodology as a tool in the discipline of social science may be demonstrated.

The models described in this thesis are based on a theoretical framework for radicalisation that has been put together by experts in the field, and they make use of data from empirical studies wherever possible to ensure that they are closely aligned to reality. It is hoped that these models will be able to further understanding of the criminality development and radicalisation processes, with the ultimate intention that models such as these could one day be useable by policy-makers and practitioners in the fields of crime and terrorism prevention to help them test the effectiveness of potential interventions so that they can use their limited budgets in the most effective way.

Understanding such complex social processes as radicalisation and criminality development so that effective interventions can be implemented is a difficult problem, and because of this it is inevitable that constructing the mathematical models will involve making simplifications that may lead to spurious results. However this research aims to show that the risk of failure is no reason not to attempt to build useable models, and that even relatively simple models can serve a useful purpose. The models developed here can be built upon with subsequent research, and with every further insight into the causes of radicalisation and criminality development they can be improved. But for that to happen there needs to be a first step, and that is what this thesis provides.

1.1 Current State of the Field

A wide range of mathematical modelling techniques already exist across a variety of fields. Some models are designed with a specific application in mind and their use never strays from that; such models are likely to have been developed within very specialist fields, such as nuclear physics or quantum field theory. However, there are many examples of models developed for one field which have then proved to be applicable to other areas. One example is the predator-prey model, the equations for which were originally developed to describe the dynamics of chemical reactions, but which were later adapted to describe the dynamics of biological systems consisting of two species where one is the predator and one is the prey. However this adaptation was not without its problems, as the predictions of the classical predator-prey model were later found to be inconsistent with field observations, resulting in the original theory needing to be re-worked and extended (Berryman, 1992).

A second example comes from the basic SIR model, used in epidemiology to describe the spread of infectious diseases such as influenza or ebola. This model can be expressed as a set of ordinary differential equations describing the rate at which people transition from state S ("susceptible") to state I ("infectious") to state R ("resistant"), with extra states added for models of diseases following different transmission patterns (Keeling and Rohani, 2008). While developed with epidemiology in mind, this SIR model has also been used to model the spread of information and ideas, and of human behaviours through imitation (Landau and Rapoport, 1953; Goffman and Newill, 1964). However these alternative models have never been validated, and have remained interesting theoretical exercises carried out by mathematicians that have been largely ignored by the world of social science.

These two cases highlight a key problem faced by the discipline of mathematical modelling as a whole: that the individuals developing the models may have a good knowledge of mathematical modelling techniques, but their knowledge of the field that the model is seeking to replicate may be lacking, resulting in a model which at best serves no useful purpose and at worst is misleading. An alternative would be to approach mathematical modelling from the other direction — for example for a sociologist to develop a model describing a social process in which they have an interest. However then there are two hurdles: firstly the sociologist needs to have an interest in developing a model in the first place, and secondly they need to have sufficient technical knowledge of different modelling techniques to build the model best suited to their needs. This first hurdle will only be cleared if the sociologist has faith that modelling can be of use to him — which is unlikely if all previous models in their field have been ineffective — while the second relies on them additionally being a polymath, a feat which is increasingly difficult to achieve in the complex world of the 21$^{\text{th}}$ Century.

A multi-disciplinary approach must therefore be taken for it to be shown that mathematical modelling can have a role to play in social science. The author hopes to demonstrate that with the right blend of technical mathematical modelling and social science knowledge this gap can be filled, even for very hard problems in social science. The research area of crime and radicalisation has been deliberately chosen as one that is of practical interest to social scientists and policy-makers, while additionally pushing the boundaries of what mathematical models can achieve in cases where data is severely limited. This thesis aims to develop models that go further than those developed by researchers such as Landau and Rapoport (1953) or Goffman and Newill (1964), by transitioning from models of purely theoretical interest to ones that could be of use to social scientists. It does this by starting not with an abstract theory or a model developed for an alternative discipline, but with the relevant social science itself.

1.2 Thesis Overview

The multi-disciplinary methodology adopted by this thesis is reflected in the approaches taken by the different chapters.

The first three chapters set the scene for the research: this introductory chapter has provided a general overview, including the motivation behind why this topic is of interest and the current state of the field. Chapter 2 focuses on the social science literature and explores the IVEE theoretical framework that will be used to underpin the models developed later in the thesis. This chapter also introduces the research question that it will be hoped that the models can answer. Chapter 3 then describes the methodology that will be followed in order to answer this research question, and in particular considers whether mathematical modelling is the right method to use.

Chapters 4 to 7 discuss the research in depth. Chapter 4 describes the process of developing the first model, which is a simulation replicating the process by which people develop the propensity to commit acts of crime. This chapter explores what data is available to quantify the relationships between different causal factors in the criminality development process, then considers how this data can be used in the model. The model then undergoes a series of stress tests in Chapter 5 to understand how it behaves when changes to its parameters and inputs are made.

Chapter 6 charts the development of a similar model describing the process of radicalisation. The development of this model follows a different approach to that of the development of the first model, due to the limited amount of data available on which the model can be based. A first attempt at answering the research question comes at the end of this chapter.

In Chapter 7 both models are extended so that they incorporate a number of interventions that could be implemented to try and prevent the spread of criminality or radicalisation. This chapter follows a similar approach to Chapter 4, as it starts by investigating what is known about interventions in the real world before considering how these interventions can be depicted in the simulations.

The final chapter brings together the insights gained from the previous four chapters to answer the research question. A discussion then follows as to whether mathematical modelling was indeed a suitable approach to answering this question, and what the limitations of the research are. Finally, further work and potential applications for the research are considered.

Chapter 2

Literature Review

The purpose of this chapter is to provide an overview of previous research that has been conducted and theories that have been developed concerning radicalisation and the process by which people develop the propensity to commit crimes more generally, with the aim of locating gaps in the current body of knowledge that this thesis can seek to fill.

This chapter is not a conventional literature review, in that it does not start with the definition of radicalisation then conduct an appraisal of all the academic literature available that uses the term. Instead, the first section of the chapter consists of a derivation of the definition of radicalisation that this thesis adopts. The wide variety of ways that researchers have used the term makes this deviation highly worthwhile. This approach allows for the scope of what is meant by "radicalisation" to be made explicit, and in particular how (or rather whether) it is distinct from the process by which people develop the propensity to commit crime, and it additionally provides the context in which the literature can be evaluated by introducing the Individual Vulnerability, Exposure, Emergence (IVEE) theoretical framework for propensity development.

The second section of this chapter looks at the IVEE framework in detail. This is then followed by an appraisal of the wider radicalisation literature, during which the IVEE framework is used to synthesise the literature and highlight any discrepancies. This section ends with a brief discussion of the relevance of ideology in radicalisation research. The chapter concludes with a review of the strengths and weaknesses of the IVEE framework when compared with other theories, a summary of the knowledge gaps pertaining to how radicalisation can be distinguished from the process by which more general criminality develops, and introduces the primary research question.

2.1 Derivation of the term “Radicalisation”

2.1.1 Definitions

This chapter has already stated an intent not to define the term “radicalisation” at this point. This is because radicalisation is an ambiguous term with almost as many definitions as there are radicalisation researchers. However, even without a formal definition, one thing that can be said about radicalisation is that it is generally considered to be a cause of terrorism. A good starting point therefore might be to define “terrorism”, but terrorism is also a term with many meanings. Instead we shall start one step further back with a definition of a more general (but related) concept — “crime”.

2.1.1.1 Crime

It is a surprising fact in the history of criminology that not much attention has been paid to what exactly crime is. In 1981 Stanley Cohen published a report on the current state of the field of criminology in Britain, in which he espoused that criminology seeks to understand the answers to three questions: “Why are laws made?”, “Why are they broken?”, and “What do we do or what should we do about this?” (Cohen, 1988, p. 9). These questions have shaped the direction criminology has taken over the course of the past three decades (Maguire et al., 2012), but in that time the question “What is crime?” has seldom been mooted.

Cohen’s three questions highlight that there is more than one approach that can be taken when defining crime: his first two questions focus on legalities, while his third question is more concerned with public policy. The dictionary definition of crime as "an action which constitutes a serious offence against an individual or the state and is punishable by law" also emphasises legalities (Oxford, 1999). But where this definition breaks down is in the lack of a universal understanding of what is right and what is wrong.

While some laws are the same worldwide, many more are culturally dependent: for example adultery is illegal in Saudi Arabia but not in the UK, although many UK citizens would still consider adultery to be *morally* wrong. The same is true of many other activities that are legal in the UK but that are considered to be unacceptable by certain groups or individuals, such as gambling and drinking alcohol. Such individuals will choose to refrain from these activities not because they face the possibility of arrest and imprisonment, but because it is against their own moral code. If they do succumb to temptation and try gambling or drinking, for them this would be akin to breaking the law. For such individuals, these behaviours — gambling or drinking alcohol — are analogous to crime. And yet some of these individuals will go ahead and carry out such activities anyway. Understanding the reasons behind why they choose to do so therefore provides some insight into why people choose to commit crime in general, but without the added complication of the impact that the risk of arrest may have on people's decision making.

The utility of studying these analogous behaviours was highlighted by Gottfredson and Hirschi in their seminal work "A General Theory of Crime" (1990). Gottfredson and Hirschi noted the resistance in criminological research to tackle the question of what crime is, and attempted "to construct a definition of crime consistent with the phenomenon itself and with the best available theory of criminal behavior" (Gottfredson and Hirschi, 1990, p. 3). They put forward that the concept of crime can be derived from the classical theory of human behaviour: that "people pursue self-interest by avoiding pain and seeking pleasure" (Gottfredson and Hirschi, 1990, p. 14). They further suggested that, contrary to the views of many earlier researchers, no distinction should be drawn between different types of crime. While the law distinguishes between a violent offence and a parking offence there is no empirical reason for the criminologist to do so, as both events require the offender to make a conscious decision to disobey their society's rules (Gottfredson and Hirschi, 1990, p. 43)

Gottfredson and Hirschi were bold in their attempt to create a general theory of crime that transcends both culture and time, and their way of defining crime has been much quoted by criminology textbooks (Maguire et al., 2007; McLaughlin and Newburn, 2010; Felson and Boba, 2010). However their definition is not without its critics. In particular, Wikström has argued against the utility of both the purely legal definition of crime and the definition suggested by Gottfredson and Hirschi. He argues that the legal definition does not make it clear what crime actually *is*, making this definition of limited use when trying to understand the reasons behind why people commit crimes (Wikström, 2011b, p. 61). However he dislikes Gottfredson and Hirschi's definition on account of the fact that it already includes an element of explanation — the pursuit of self-interest.

Wikström argues for a definition of crime that clearly delineates between a cause and its resulting effect. His solution is to consider crime as a *moral action* — that is, an action guided by rules that state what is the right or wrong thing to do in a particular circumstance — and he defines crime to be "the breach of a moral rule of conduct stated in law" (Wikström, 2011b, p. 62). Wikström defends his position by arguing that the concept of crime as "moral rule-breaking" is more precise than concepts such as "delinquency" or "antisocial behaviour", and that it makes clear that such rules may vary across time and space (Wikström, 2009b, p. 63).

Wikström's definition addresses the difficulties posed by the purely legal definitions of crime, as it focuses on an individual's own sense of morality rather than just the morality enshrined in legislation. His definition's focus on rule-breaking also treats crime purely as an effect, not a cause, eliminating any potential ambiguities that may emerge when seeking to understand the causes of crime. For these reasons, this is the definition this thesis will use.

2.1.1.2 Terrorism

Definitions of terrorism are many and varied, as are acts of terrorism themselves. Violent acts such as shootings, bombings and arson are clearly crimes in their own right. In the UK, non-violent terrorist activities such as joining a global terrorist organisation and the distribution of extremist material have also been criminalised in specific legislation, such as the Terrorism Act 2000 and Terrorism Act 2006 (Simcox et al., 2010). Terrorist offences are therefore enshrined in law in the same way as any other crime. So what makes terrorism distinctive?

Elworthy and Rifkind consider terrorism to be "a tactic rather than a definable enemy" (2006, p. 27): terrorism is a means to an end, and that means happens to be a violent criminal one. Shaftoe et al. (2007) among others agree, noting that terrorism is above all a crime, that acts of terrorism should be treated as such through the criminal justice system, and that in order to prevent terrorism happening practitioners need to understand what makes people offend and what makes people desist. In this sense, these researchers consider terrorism to be no different from any other crime.

However some academics do put more emphasis on terrorism's differences rather than similarities with other forms of crime. Victoroff examined many definitions and noted two underlying principles across them all: that of aggression against non-combatants, and that the action is not intended to accomplish a political goal in itself but instead to influence and change the behaviour of a target audience (2005, p. 4). But do these principles mean that acts of terrorism should be considered distinct from other crimes?

Recall that in this thesis crime is defined to be the breaking of a moral rule that is enshrined in law. If we take terrorism to be a concept entirely distinct from crime, what would an equivalent definition of terrorism look like? Victoroff's first principle — that terrorism consists of aggression towards non-combatants — requires no alteration of our definition of crime: aggression towards non-combatants is certainly an act that breaches moral rules in most (if not all) human societies. Victoroff's second principle is however more interesting, as it refers to the intention behind the criminal (terrorist) act. But all offenders will have some form of intention behind their criminal activity, be it financial gain in cases of armed robbery, personal power for many domestic violence cases, or influence in cases of blackmail (Taylor and Horgan, 2006). These different intentions do not alter the definition of the offender's actions as being crimes. The effect that different intentions might have would be on the offender's sense of morality and the way their propensity to commit a crime or an act of terrorism has developed. Therefore what makes terrorism different from other crimes is how the offender's criminal propensity develops, not the act of terrorism itself. This distinction is highlighted by the fact that the development of an individual's propensity to commit acts of terrorism is given a name — "radicalisation" — while no equivalent term exists for individual propensity development in the case of general crime.

In summary, terrorism is the word used to describe crimes perpetrated by individuals whose intent is to influence or change the behaviour of a target audience using methods of fear or intimidation of non-combatants. A terrorist act is therefore just a normal criminal act, but the causes behind the act may be different. This will be explored in the next section.

2.1.2 Causes of Crime

Before considering the causes of crime (including terrorism) it is important to draw a distinction between causation and correlation. Correlation merely demonstrates that two variables are related: that when one goes up in value the other also goes up in value, for instance. However causation requires more than merely being able to predict the outcome of one variable from another variable: for example, a barometer predicts weather conditions, but it does not cause them (Wikström, 2011b, p. 57). In that particular example, it is a change in atmospheric pressure that causes both the reading on the barometer and the change in the weather; the barometer reading is therefore a *marker*, not a cause, of a change in weather.

It is not possible to consider causes without also considering effects. A cause must be a cause *of* something. An effect can be anything for which an explanation is sought — an increase in antisocial behaviour, for example, which may have a number of causes that a researcher might want to identify. But how can one tell whether a variable correlated with this effect is a marker or a cause? The answer lies in *how* the cause and the effect are related, not the mere fact that they *are* related. This "how" is the *causal process*, which is a mechanism that not only provides a logical link between the cause and the effect, but also brings about the effect (Wikström, 2011b, p. 58).

2.1.2.1 Proximal Causes of Crime

Where the logical link between a cause and an effect is direct, we call this a *proximal* cause. An example from the physical sciences is that heating a gas results in it expanding: the mechanism by which this happens is through the increase in the kinetic energy of the molecules that comes with the increase in temperature. However, this effect on the volumne of gas only happens if pressure is kept constant; if the gas is heated and simultaneously the pressure is increased, the gas will not expand in the usual way. This is an example of a *causal interactions*.

In the social world causal processes are rarely simple, and there are generally many factors and many causal interactions to take into consideration. The factors and interactions that make up the proximal causes of crime are a key research interest of environmental criminologists, and a number of theories have emerged from this school such as routine activity theory (Cohen and Felson, 1979), crime pattern theory (Brantingham and Brantingham, 1993), and rational choice theory (Cornish and Clarke, 1986). The first of these, routine activity theory, suggests that it is the routine day-to-day activities of offenders and victims that lead them to be in certain places at certain times, and that it is the convergence of a motivated offender and a suitable target at the same place and the same time (and with no capable guardians present) that causes crime to happen. These three elements — the offender, the victim, and the place — have been called the "crime triangle" by environmental criminologists (Clarke and Eck, 2003). Crime pattern theory extends these ideas; this theory notes that spatial patterns of crime are not random, and that crime is more likely to occur where the "activity space" of an offender overlaps with the activity space of a potential victim. Rational choice theory concerns the decision making of the offender: it assumes that offenders are rational actors who weigh up the costs and benefits of their decisions before they choose to offend.

Applying these ideas to an example, one can put forward a hypothetical argument that football matches cause an increase in pick-pocketing. In order for the presence of a football match to be a cause rather than a marker of pick-pocketing there also has to be a causal mechanism; this could be that the football match results in large crowds, which provides plenty of targets and cover for pick-pockets, attracting them to the location. As the crime triangle illustrates, for pick-pocketing to happen there needs to be an offender present, some potential victims, and an appropriate environment in which the offence can take place; it is the confluence of these three elements at the same time, brought about as a result of the football match, that causes the increase in pick-pocketing.

The precise confluence of these elements varies enormously from crime to crime, but it can always be argued that crime occurs as a result of an offender encountering a particular setting, and therefore that the immediate cause of crime "is *always* a question of a person-environment causal interaction" (Wikström, 2011b, p. 58). It should therefore come as no surprise that terrorism — as a form of crime — has similarly been observed to be "a product of its own place and time" (Post, 2005).

2.1.2.2 Situational Action Theory

Situational Action Theory (SAT) is a general theory of crime causation proposed by Wikström that builds upon these ideas. It seeks to explain why people choose to breach moral rules. The question of why people commit crime then becomes a special case of the more general theory explaining the breaches in moral rules: it is simply the cases where the moral rules that are broken have been enshrined in law

(Wikström, 2009b, p. 63). SAT argues that crime — the breaking of moral rules enshrined in law — is an action that an individual may choose to take when interacting with a certain environment. When the individual is in that environment they will perceive a number of different *action alternatives*, and if one of these action alternatives is to commit a crime then they may then choose to do so (Wikström, 2009b, p. 93).

To return to the football match example, a person who carries out the act of pick-pocketing at a match will have both identified that pick-pocketing is an action alternative and chosen to carry it out. This tells us something about their sense of morality and their levels of self-control: they may consider pick-pocketing to be a perfectly acceptable act, or they may accept that it is morally wrong but decide to do it anyway because of the ease of carrying out the act in a large crowd and the low risk of being caught. Wikström notes these two attributes — morality and a person's ability to exercise self-control — as the key components in a person's *criminal propensity*. Many previous researchers have shown that these personality traits are strongly correlated with criminal activity (Gottfredson and Hirschi, 1990; Grasmick et al., 1993; Pratt and Cullen, 2000; Hawkins et al., 1998; Jan Stams et al., 2006), but Situational Action Theory explains *why*.

However it is not merely the presence of a person with the propensity to pick-pocket that causes the crime to take place. As the crime triangle shows, there also needs to be an appropriately criminogenic setting and some potential victims. These are the *situational factors* that need to be present for an individual with the right propensity to choose to commit a crime then and there. And so, according to SAT, the direct causes of crime are an individual with a sufficient criminal propensity, and the right environment.

2.1.2.3 Causes of the Causes

One criticism of SAT is that it is entirely focussed on the present and ignores broader social conditions that are associated with higher levels of crime, such as poverty, low levels of education, and family break-up. Wikström's defence is that these factors are the *causes of the causes* of crime; they should certainly not be ignored, but as their effect on crime is indirect they do not form part of the SAT model. SAT is concerned with the direct proximal causes of crime, being the interaction between a person's criminal propensity and their environment, resulting in an act of crime. The causes of the causes are what leads the person to have such a criminal propensity in the first place, what makes a setting criminogenic, and what causes the person to be present in the setting. Wikström refers to these as "person emergence", "social emergence", and "selection" respectively (Wikström, 2011b, p. 69).

As previously discussed, a person's criminal propensity can be broken down into their morality and their ability to exercise self-control. What causes "person emergence" to happen can therefore be divided into the process of a person's moral education, and the process of the development of cognitive skills relevant to self-control (Wikström, 2011b, p. 69). The underlying causes of each will vary from person to person and may be biological or environmental in origin, or a combination of both (the well-known "nature versus nurture" debate). But the causes will be specific to each person.

"Social emergence" is the question of how a setting becomes criminogenic — that is, what is it about the setting that encourages those with a propensity for crime to go there and commit crime. This question has two sides: firstly, which wider environmental factors are relevant to making a setting criminogenic, and secondly, how do certain settings become distinct from other settings in relation to these factors, and thus become more criminogenic (Wikström, 2011b, p. 69). Relevant factors could include levels of heterogeneity in the population, residential segregation, or the amount of official monitoring of certain settings. These factors are broad in their nature, as the causes of social emergence lie in factors that affect wider society. These indirect causes thus operate at the systemic level.

"Selection" refers to the processes that lead certain people to be present at certain settings. There could be a variety of reasons why people go to certain settings, including both individual factors such as habits and lifestyle preferences (which themselves are the outcome of a social process), and socio-demographic factors such as age, occupation, religion and ethnic group (Wikström, 2011b, p. 70). Selection has a role both as a direct and an indirect cause of crime: if the settings an individual chooses to go to are criminogenic then the individual may decide to commit a crime there (the direct cause). But even if they do not commit crime when at a criminogenic setting, they will still become exposed to criminogenic moral contexts, which may influence their moral development (the indirect cause).

The causes of the causes of crime can therefore be considered to comprise three levels: the individual level, the ecological level, and the systemic level. The individual level is concerned with the impact of a person's individual vulnerability, consisting of their moral development, ability to exercise self-control, and individual factors that influence selection such as lifestyle preferences. The ecological level relates to the environment — the settings to which a person becomes exposed, and in particular criminogenic ones. The systemic level is about the wider societal issues that lead to the emergence of criminogenic settings. All three levels are necessary to provide a full explanation for the causes of the causes of crime.

2.1.3 What is "Radicalisation"?

The previous section presented the three levels of the causes of the causes of crime, which illustrate how an individual can develop the propensity to commit crime when they are in a setting conducive to criminal behaviour. Separately the argument has been put forward, supported by Elworthy and Rifkind (2006) and Shaftoe et al. (2007) among others, that terrorism is simply a type of crime — albeit a crime that has a specific underlying reason behind it. By combining these ideas, a definition of radicalisation presents itself: *radicalisation* is the process by which an individual develops the propensity to commit an act of terrorism (Bouhana and Wikström, 2011).

As with more general crimes, the process by which an individual's propensity to commit acts of terrorism develops is a "cause of the cause" of crime (specifically terrorism), and is a slow, developmental process. If the assumption is made that the process of radicalisation is analagous to the process by which criminal propensity develops, the three levels described in the previous section can be used to synthesise what is known about radicalisation from the wider literature (Bouhana and Wikström, 2011). Bouhana and Wikström used the three levels to create a model of radicalisation called the *Individual Vulnerability, Exposure and Emergence (IVEE) theoretical framework* for this very purpose.

2.2 The IVEE Theoretical Framework for Radicalisation

In this section the three levels of IVEE — individual vulnerability, exposure, and emergence — will be explored in more detail to establish what each represents, how the causal factors are linked, and ultimately how each contributes to the process by which radicalisation happens.

2.2.1 Individual Vulnerability

In the context of IVEE the term "individual vulnerability" specifically refers to an individual's vulnerability to a change in their propensity to commit an act of terrorism, where propensity comprises the individual's level of morality and their ability to exercise self-control. There are two factors that need to be present for a change in individual vulnerability to happen: the first is for the individual to be *cognitively susceptible* to being influenced by a radicalising moral context when they have been sufficiently exposed to one, and the second is for them to find themselves in an environment where such a context exists, or *susceptibility to selection*.

2.2.1.1 Cognitive Susceptibility

Individuals who are cognitively susceptible to developing the propensity to commit terrorist acts display specific cognitive difficulties. These cognitive difficulties make them less able to exercise self-control, and more easily influenced by radicalising moral contexts. But what makes some people more likely to suffer these difficulties than others?

This first issue, an inability to exercise self-control, is a consequence of impaired cognitive skill development (Bouhana and Wikström, 2011). Previously, some criminologists including Gottfredson and Hirschi in their seminal work on constructing a general theory of crime, had supposed capacity to exercise self-control to be environmentally-driven. However more recent work in the field of neuroscience has questioned this and suggested that there may be a genetic component.

Neuroscientists have determined that capacity to exercise self-control resides largely in the brain's prefrontal cortex (Beaver et al., 2007). The co-ordinated actions of the prefrontal cortex are known by neuropsychologists as "executive functions", and capacity for self-control is just one of a larger cluster of functions such as planning, cognitive flexibility, and decision making, all of which reside in this part of the brain (Suchy, 2009). The prefrontal cortex is the last part of the brain to develop, only becoming fully mature when an individual is in their early to mid-20s, which does potentially support Gottfredson and Hirschi's theory that self-control develops in accordance with an individual's environment. However, in a study on American kindergarten children, Beaver et al. (2007) found that problems with capacity to exercise self-control were largely already determined by the time children start school.

This finding does not necessarily contradict the possibility that capacity to exercise self-control arises from environmental factors; brain development starts in the womb, and exposure to toxins such as alcohol and other drugs during gestation can impede brain growth and lead to later problems in executive functioning. However, findings from twin studies have largely invalidated this theory, with one study conducted on 17 year old American youths finding that differences in executive functions are "almost entirely" genetic (Friedman et al., 2008).

The second feature of a cognitively susceptible individual is that they are more easily influenced by radicalising moral contexts. This is essentially a matter of differences in a person's moral education (Wikström, 2011b, p. 69). But from where might such a difference originate? Moral psychologists believe that moral reasoning comes from a combination of an intuitive or affective response, and a reasoned or cognitive response (Haidt, 2001; Greene and Haidt, 2002). Of these two reactions to a situation the affective response occurs first, with the cognitive response happening in slower time: a person will first feel a "gut" reaction to a situation, and then use their reasoning to either justify this reaction or override it. If they have reasoned their way to a different response from the initial affective response, when faced with the same situation another time their affective response may have changed accordingly. A change in morality thus comes about as a result of a considered argument for a different course of action than the one initially supported. This may emerge from an internal thought process, or from discussing the situation with other people who offer a different perspective (Haidt, 2007). This latter reason depends on the ability of other people to influence the individual, and in the context of IVEE relates to how radicalising the setting is to which the individual is exposed. But in the former case — an internal thought process — people are more likely to change their minds when a situation activates certain brain regions associated with internal conflict (specifically, the anterior cingulate cortex and the dorsolateral prefrontal cortex), which makes them slower to respond (Greene et al., 2004).

A review of neuropsychological studies into morality conducted by Fumagalli and Priori offers further insight into which parts of the brain are responsible for different aspects of morality, again highlighting in particular the roles of the anterior cingulate cortex and parts of the prefrontal cortex (2012, p. 2008). The key conclusion of importance for this thesis is that a brain network for morality does exist, and thus that an individual's cognitive susceptibility to moral change is at least in part due to biological factors. Fumagalli and Priori's work also notes that the brain regions affecting morality are different for those diagnosed with psychopathy than they are for the general population, suggesting that it is perfectly possible for someone to be highly cognitively susceptible to moral change without them showing signs of psychopathy. This supports the observation that neither criminals nor terrorists are generally psychopaths.

It should also be noted that these two cognitive traits — differences in capacity to exercise self-control and in morality — are not entirely independent of each other. In particular, Gino et al. (2011) conducted research into the effect that reducing people's capacity to exercise self-control has on their moral behaviour. The authors of this paper made two relevant findings: firstly that an individual's reserves of self-control do get depleted when the individual is continually exposed to situations where they are have to exercise restraint, and secondly that when the person's self-control reserves have been depleted, they are more likely to behave unethically. These are significant findings for the current research, as they demonstrate that even an individual with great capacity to exercise self-control will still be influenced by radicalising moral contexts if they receive enough exposure. Gino et al. did however note one important exception, which is that individuals with very high personal moral standards are less influenced by self-control depletion. The authors suggested that this may be because such individuals "have strongly internalized moral standards and thus do not need to expend cognitive resources when thinking through the decision of how to resolve ethical dilemmas" (2011, p. 193).

To summarise, it is possible to present a biological definition for what it means for someone to be cognitively susceptible to moral change, which is that the person's anterior cingulate cortex and dorsolateral prefrontal cortex are more likely to be activated when presented with a difficult situation. When this is combined with impaired executive functioning skills, indicative of an inability to exercise self-control, this describes the cognitive condition of a person who would be highly susceptible to radicalisation.

2.2.1.2 Self-Selection and Lifestyle Choices

An individual's susceptibility to selection is also a key component of their individual vulnerability, as an individual may be inherently persuadable, but if they never come into contact with a radicalising moral context they will never develop the propensity to commit terrorism. The personal characteristics that lead someone to be more likely to come into contact with radicalising environments include socio-demographics, social networks, and the person's lifestyle preferences such as whether they enjoy a trip to the pub or visiting bookshops (Wikström, 2011b, p. 70).

Self-selective factors are difficult to model precisely, as by their very nature they are individualistic. However, one logical hypothesis that can be put forward is that a person is more likely to want to go to locations where similar people also go. This is a phenomenon called homophily: that a person seeks out like-minded company (Kandel, 1978; Kandel et al., 1990). It can also be assumed that individuals are more likely to go to places that are located closer to where they live or work — their "activity space", to use the language of routine activity theory. Additionally, a place that attracts a larger number of people will attract people from a wider catchment area, so the size of the setting may also be an important factor influencing a person's decision to go there.

2.2.2 Exposure

For exposure to radicalising settings to happen there is a requirement both for radicalising settings to be present, and also for the individual to find themselves in their vicinity. Selection is therefore key to exposure, as is the environment itself. Self-selective factors were covered in the previous section under Individual Vulnerability, but the ecological level provides further selective factors through socio-demographics — this is *social selection*.

The concept of an individual's *activity field* is a useful way to explain the exposure aspect of the IVEE framework. An activity field is the configuration of different settings to which a person is exposed during a given time period (Wikström et al., 2010, p. 59). Analysis of the activity fields of adolescents has enabled conclusions to be drawn regarding the effects that exposure to criminogenic settings has on the likelihood that the adolescents commit crime (Wikström et al., 2010). An individual at a higher risk of developing the propensity for crime is one whose activity field leads them to encounter a higher number of criminogenic settings, resulting in that individual finding themselves repeatedly exposed to criminogenic moral contexts. An activity field can be represented as an array or a table of settings for each person, where each entry in the table indicates the likelihood that the person visits that setting.

The concept of an activity field is very similar to the idea of an activity space in routine activity theory (Cohen and Felson, 1979). While RAT seeks to explain the proximal causes of crime rather than the distal developmental causes that IVEE is seeking to explain, the fundamental idea of an activity field or an activity space as being a representation of where people spend time on a day-to-day basis is the same.

2.2.2.1 Social Selection

An individual may find themselves in the vicinity of a radicalising setting due to their own social networks or lifestyle preferences, as already discussed. However preferences work at the ecological level as well as the individual level, as members of particular groups are more likely to find themselves in some settings than others: for instance, students will be more likely to attend special interest groups on a university campus, while Muslims will more likely go to a mosque or Islamic community centre. This form of selection, social selection, constrains self-selection by determining the settings in which an individual is most likely to find themselves.

2.2.2.2 The Environment

Of course, one cannot consider either self- or social-selection without considering the wider environment in which the person's activity field is situated (Bouhana and Wikström, 2011; Wikström et al., 2010). For instance, a university student at a rural campus may have a similar daily pattern to a university student in the centre of a large city in terms of how long they spend at lectures, in halls, or socialising. But the likelihood that they encounter radicalising settings in the course of their daily lives would likely be very different.

Radicalising settings can be either physical spaces such as a café or a leisure centre, or they can be virtual settings such as web forums. These locations attract individuals with the propensity for terrorism because they offer some degree of privacy (or at least the perception of privacy), enabling these individuals to carry out illegal activities without interruption or identification.

The local environment forms a key part of the exposure element of IVEE, as a person cannot be exposed to radicalising moral contexts unless they are located in places the person actually visits. However the question of how these radicalising moral contexts come to appear in any particular environment is a question of *emergence*.

2.2.3 Emergence

The final element in the IVEE framework is concerned with how radicalising settings emerge. Some settings are evidently more radicalising than others: for instance Al Qa'ida's recruiters are more likely to hand out leaflets near a mosque than at a rural village fête. But what features of a setting lead to it becoming an attractive location for those with the intent to radicalise?

A setting can be considered radicalising if a radicalising moral context is routinely found there (Bouhana and Wikström, 2011). Some of these contexts are not physical locations — websites, for example, or even television programmes that normalise types of terrorist behaviour. However as radicalising settings are thankfully extremely rare, the reasons behind why some settings become radicalising and other do not is under-researched. Some parallels can however be drawn with the emergence of criminogenic settings — that is, settings in which a criminalising moral context is routinely found (Wikström and Treiber, 2009; Wikström, 2011b).

A number of suggestions have been put forward for why certain settings become criminogenic while others do not. One of these comes from *social disorganisation theory*, a sociological theory developed in the 1940s that became a popular explanation for why crime rates vary across different locations (Shaw and McKay, 1942).

Social disorganisation theory argues that certain community-level variables that had been shown to be correlated with increased crime rates, such as the socio-economic status of local inhabitants and ethnic heterogeneity, only have an indirect effect on crime. According to the theory, such variables have a direct effect on the level of social disorganisation in the area, and it is this social disorganisation that leads to increased levels of crime (Sampson and Groves, 1989, p. 783).

Sampson and Groves (1989) sought to test the veracity of this theory using data from the 1982 British Crime Survey. Their research tested two links: the first is the link between five exogenous factors thought to lead to social disorganisation (low socio-economic status, ethnic heterogeneity, residential mobility, family disruption and urbanisation), and three variables used to measure social disorganisation (sparsity of local friendship networks, low levels of participation in local organisations, and high numbers of unsupervised teenage peer groups). The second is the link between these social disorganisation variables and crime.

The crime variable was measured both by victimisation numbers and self-reports of offences. This distinction is important because it tells us something about the locations of the offences themselves (and therefore the situational factors) versus locations that influence an individual's propensity for crime (developmental factors). If the social disorganisation variables were shown to have a statistically significant effect on victimisation levels that would suggest that offences are more likely to take place in settings that suffer from social disorganisation — meaning that social disorganisation is a cause of the *situational* factors leading to crime. However a link between the social disorganisation variables and self-reported offences (which would not necessarily take place in the neighbourhood in question) would suggest that exposure to socially disorganised settings affects the *development* of the offenders' crime propensity.

Sampson and Groves concluded that there were statistically significant relationships between all three social disorganisation variables and the victimisation data. However only two of the social disorganisation variables affected self-reports of offences: the presence of unsupervised teenage peer groups and the density of local friendship networks. Organisational participation had an effect on victimisation levels but not on self-reports of offences, suggesting that local participation in such groups may counter crimes at the situational level, but may also cause a displacement effect, with offenders more likely to commit offences outside the community.

More recent research by Sampson (2004, 2009) has superseded his previous results on the effects of social disorganisation on crime. This came as a result of a new concept called *collective efficacy*, dubbed the “offspring” of social disorganisation theory (Sampson, 2009, p. 41), and originally developed by Sampson et al. in 1997. Collective efficacy is defined to be “social cohesion among neighbors combined with their willingness to intervene on behalf of the common good”. Collective efficacy theory considers that certain exogenous factors lead to a lack of order and cohesion in a community, and making that community more likely to develop unmonitored locations that could become safe havens for those engaging in crime. The factors regarded as likely to cause a lack of collective efficacy are high levels of segregation, sparsity of social ties, sparsity of local organisations/civic structures, and “routine activities” — that is, how the ecological distribution of daily routine activities affect crime (Sampson, 2009).

There is evidently some overlap in the indicators of collective efficacy and social disorganisation. Sampson acknowledges this, but considers social disorganisation to be a marker for low collective efficacy, in the same way as crime itself is, and that collective efficacy is the true causal factor behind the emergence of criminogenic settings (2009, p. 51).

2.2.4 The Complete IVEE Framework

The interactions of the causal factors making up the IVEE framework can be summarised as a flowchart, as shown in Figure 2.1 (Bouhana and Wikström, 2011).

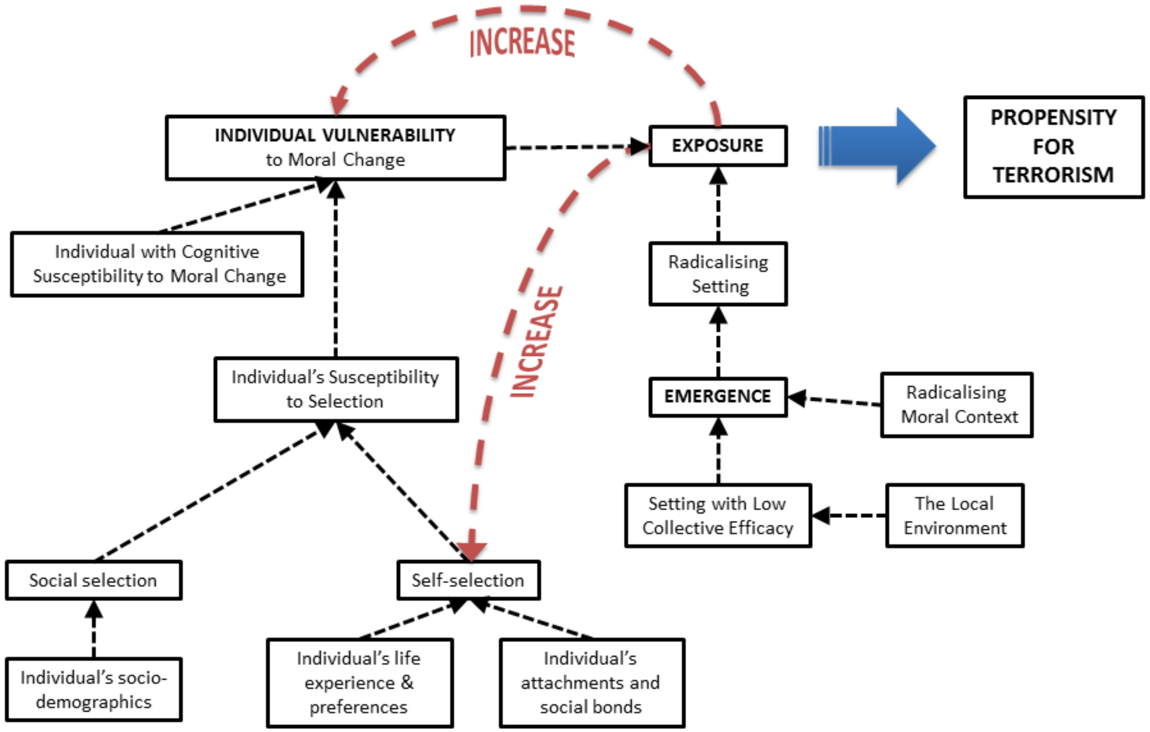


Figure 2.1: The IVEE model of radicalisation (Bouhana and Wikström, 2011). The left half of the diagram shows how socio-demographic, cognitive and selective factors contribute to an individual's overall vulnerability to moral change. The right half of the diagram shows the environmental factors that contribute to the emergence of a radicalising setting, with the top right quadrant indicating that when a vulnerable individual becomes exposed to such a setting they develop an increased propensity to commit acts of terrorism. The red arrows indicate parts of the model affected by feedback: increased exposure to radicalising settings increases the self-selective factors contributing to an individual's vulnerability to moral change, and also increases that vulnerability directly.

2.3 Radicalisation Literature Review

This section comprises a literature review of radicalisation research. The subsections below are structured so that each introduces a different theory behind radicalisation that has been suggested by academics from different fields of study. For theories where a complete explanation for radicalisation has been proposed the IVEE framework will be used to analyse the theory and identify any areas of contradiction or where current knowledge is lacking. This also allows for the IVEE framework to be compared with alternative theories.

2.3.1 Moral Shocks

A number of convicted Islamist terrorists have cited as the reason for their radicalisation some atrocity in which they consider Western governments to be complicit. For example, O'Duffy relates the story of Nizar Trabelsi, a Tunisian arrested for plotting an Al Qa'ida bombing mission against US Forces (O'Duffy, 2008, p. 37). Trabelsi told the court at his trial that he was inspired to become a martyr for Bin Laden after he saw pictures of a Palestinian infant girl killed by Israeli forces in Gaza in 2001. A second example comes from Ed Husain's autobiographical account of his involvement with the Islamist movement, when in 1993 he used a video depicting the ethnic cleansing of Bosnian Muslims to encourage students to become involved with the Islamist cause (Husain, 2007). The importance of such "moral shocks" is a known recruitment tool for other extremist movements too: in their research on the animal rights and anti-nuclear protest groups Jasper and Poulsen (1995) observed that those recruited into these social movements would either join due to their existing social networks, or following a moral shock. These moral shocks instil a sense of purpose in an individual and cause them to seek a way to take action, which the individual then does by joining the movement.

However a moral shock can only take a person so far down the path of radicalisation. These shocks may cause them to join a movement, and may be cited afterwards as the individual's reason for committing terrorist offences, but across the radicalisation literature it is recognised that there is more to the process than this. Very few people could honestly say that they have never experienced a moral shock — the 11 September 2001 attacks or the Beslan school massacre in 2004 are clear examples that horrified the Western world. But for the vast majority these shocks do not cause a change in their morality or behaviour. So why are some people affected differently from others?

2.3.2 Rational Choice Theory

One key question is whether those who have been radicalised had a pre-disposition to terrorism prior to being exposed to the radical narrative. Are those who are radicalised inherently different from the rest of us on a psychological level? Many psychologists have explored this question, with the consensus being that terrorists in general do not suffer from psychopathy (Victoroff, 2005; Post, 2005; Borum, 2011b; Pisoiu, 2013). The actions of terrorists may seem insane from the point of view of an outsider, but terrorists do behave rationally in the sense that (to them) they are making logical decisions. This observation is supported by Rational Choice Theory, a theory promoted by criminologists Cornish and Clarke (1987) who considered criminals to be rational actors able to weigh up the costs and benefits of participating in crime. When applied to terrorism, Rational Choice Theory considers terrorist action to come from a conscious, calculated decision that carrying out the action is the optimum strategy to achieve a socio-political end (Victoroff, 2005, p. 14).

If one assumes Rational Choice Theory to be correct, the question of why some people become radicalised and others do not becomes instead one of why some people consider terrorist action to be a rational alternative and others do not. But rationality itself is very subjective, in that two rational people can decide on different actions because they consider different things to be important. For example, suppose two people have the same journey to work and the same information about the health benefits and risks of cycling. Based on this information Person A chooses to cycle to work because of the health benefits, while Person B opts for the bus because they fear becoming involved in a road traffic accident if they cycle. Neither decision is necessarily more rational than the other, but the two people have come to different decisions over whether to cycle because they have different attitudes to risk. By thinking about radicalisation in similar terms it becomes easier to understand why, when exposed to a moral shock or radical narrative, some people become motivated to take action in response while others do not (Purves et al., 2008, p. 606).

This individuality becomes even starker when one considers the different starting points terrorists have. Terrorists come from a multitude of different socio-economic, ethnic, and religious backgrounds, and one cannot assume that individuals belonging to certain sectors of society are more vulnerable to becoming radicalised than others (Sageman, 2004; Victoroff, 2005). Even if this were the case, the problem of specificity still applies, as Githens-Mazer and Lambert (2010) discovered when they explored the case of two brothers with the same upbringing and exposure, only one of whom went on to become involved with terrorism. Every person's experience of radicalisation is highly individual (Wilner and Dubouloz, 2010, p. 38).

2.3.3 The Conveyor Belt Theory and Radicalisation Pathways

From the previous two sub-sections it can be concluded that a moral shock can provide the trigger for someone to join a group that provides them with radicalising influences, and that those who have been radicalised are rational actors making choices that seem, to them, to be logical ones. But neither theory has yet provided a coherent explanation for *what is actually happening* when somebody experiences radicalisation.

One theory that has gained media attention (Elliot, 2002; Malik, 2005; The Week, 2015) and traction among some US Government organisations (U.S. Department of State, 2006) following 11 September 2001 is the idea of radicalisation as a conveyor belt, whereby an individual who feels a grievance starts along a trajectory that ends in violence (Moskalenko and McCauley, 2009). Supporters of this theory suggest a mechanism which sees terrorist recruiters deliberately seeking "to convert alienated or aggrieved populations, convert them to extremist viewpoints, and turn them, by stages, into sympathizers, supporters and, ultimately, members of terrorist networks" (U.S. Department of State, 2006). This suggests someone who holds "extreme" views but has never committed any acts of violence is on the way to becoming a terrorist.

Proponents of this view suggest that non-violent activist groups that hold extreme views provide a fertile recruiting ground for terrorist organisations. However opponents highlight that attitudes and behaviours are different, and that non-violent activist groups who hold the same views as terrorist organisations actually provide an alternative outlet for people (Moskalenko and McCauley, 2009, p. 240). For example, the radical Islamic group Hizb ut-Tahrir al-Islami has been regarded by some as an organisation that contributes to violence and requires surveillance; others suggest that Hizb ut-Tahrir competes with Al-Qa'ida, as both are trying to recruit from the same pool of individuals, with Hizb ut-Tahrir providing a non-violent option (Karagiannis and McCauley, 2006).

Moskalenko and McCauley conducted a study to establish which school of thought was better supported by empirical evidence; their methodology suffered from a lack of rigour as they measured only the intentions of participants rather than their actions, but their results showed conclusively that it is only a small minority of those with "activist" (non-violent) intentions that also have "radical" (violent) intentions (2009, p. 256). It is reasonable to suppose that even fewer of those with violent intentions actually went on to carry these out. Moskalenko and McCauley concluded that the evidence refutes the conveyor belt theory, and considered it to be an "unhelpful metaphor".

2.3.4 Radicalisation as a Multi-Stage Process

Despite its shortcomings, the conveyor belt theory does introduce the notion of radicalisation as a *pathway*. The pathway approach has been endorsed by psychologists Taylor and Horgan who, having noted that the state of being a terrorist is not in itself a psychopathology, have pushed for researchers to move away from profiling terrorists and instead to view involvement in terrorism as a process (Taylor and Horgan, 2006; Horgan, 2008). Taylor and Horgan define a process to be a "sequence of events, involving steps or operations that are usually ordered and/or interdependent", however they distinguish this from the conveyor belt metaphor by emphasising that the elements of the process do not need to follow each other deterministically (2006, p. 586). They add that there is not one single route to terrorism, and that every individual who is radicalised follows their own trajectory. But despite these individualised trajectories, researchers have attempted to synthesise the data from actual cases of radicalisation and produce a definitive description of what the radicalisation process looks like. Many of these have taken the form of multi-stage process.

One example of these mutli-stage processes comes from Silber and Bhatt, who produced a report for the New York City Police Department in which they provide a simple and much-quoted four stage process for (Islamic) radicalisation:

- Stage 1: Pre-radicalisation, consisting of the period before people become exposed to jihadi-Salafi Islam;
- Stage 2: Self-identification, when people come to associate themselves with the ideology;
- Stage 3: Indoctrination, where their belief deepens and they decide action must be taken; and
- Stage 4: Jihadisation, when they consider themselves to be holy warriors or mujahedeen. (Silber and Bhatt, 2007)

In another example, Wiktorowitcz applied social movement theory to the phenomenon of recruitment to militant jihadist groups and also developed a four stage process. These four stages are:

- Stage 1: Cognitive opening, whereby an individual becomes receptive to new ideas;

- Stage 2: Religious seeking;
- Stage 3: Frame alignment, where the narrative of the radical group "makes sense" to the individual;
- Stage 4: Socialisation into the group. (Wiktorowitcz, 2005)

These two examples are the most cited multi-stage processes in the radicalisation literature, and have been developed by individuals who are well-respected in the field, either through experience as practitioners (in the case of Silber and Bhatt) or through an extensive academic career (Wiktorowitcz). How do they sit with the IVEE framework?

Taking Silber and Bhatt's process first. Recall that in this thesis radicalisation is defined to be the development of an individual's propensity to commit an act of terrorism. As explained in Section 2.1.2.2, an individual has a propensity to commit an act of crime (or terrorism) if, when in a particular situation, they see a criminal (terrorist) act as one of their action alternatives and choose to carry out this act. This propensity develops through the individual's moral education, and through the development of their cognitive skills in relation to their ability to exercise self-control.

Examining Silber and Bhatt's process in detail, Stage 1 is actually the point before the person starts on the path to radicalisation, and therefore does not form part of the process itself. Stage 2 is about the individual identifying with an ideology. The concept of "ideology" will be explored in greater detail later, but the way Silber and Bhatt use the term here, its importance lies in the way it affects an individual's lifestyle preferences, leading them to choose to spend time in particular settings and with particular (probably like-minded) people. In the language of IVEE, Stage 2 is thus about selection. Stage 3, indoctrination, is where the person decides to take action. Relating this to the IVEE framework indoctrination can be considered as the individual having received sufficient exposure to a radicalising narrative for their morality to start to change. Stage 4 then sees the completion of this process.

Wiktorowitcz's process refers to recruitment rather than radicalisation, but by examining it through the lens of the IVEE framework we can explore whether any parts of this process relate to radicalisation as this thesis has defined it. Stage 1, where an individual becomes receptive to new ideas, clearly relates to the individual's vulnerability at a psychological level. While Wiktorowitcz's process does not consider how such a cognitive opening happens in the first place, through IVEE it can be surmised that it may have been as a result of the individual being exposed to ideas that challenge them — a moral shock or a radical narrative, for example — and make them wish to explore these ideas further (selection). Stage 2, religious seeking, is about exactly that — the individual's deliberate search for new ideas, causing them to potentially increase their exposure to radicalising moral contexts. The concept of "frame alignment" in Stage 3 is an idea that originates in social movement theory, and has been explored by a number of political sociologists interested in radicalisation. It therefore deserves its own discussion (see the following section). The final stage is socialisation into the group; again this relates to the amount of exposure the individual gets to radicalising moral contexts. The more integrated an individual is into a group, the more time they will spend with them, and the more likely it is that the group's ideas will penetrate the individual and influence their sense of morality. For law-abiding activist groups this would not result in radicalisation, but for groups intent on carrying out acts of terrorism it could.

2.3.5 Social Movement Theory

The previous section introduced the idea of frame-alignment as part of Wiktorowitcz's four stage recruitment process. Wiktorowitcz comes from the school of political sociologists that promote the use of social movement theory as an explanation for terrorism and political violence. Social movement theory is interested in large groups — "social movements" — and examines individuals' relationships with such groups, and the groups' relationships with society (Crossett and Spitaletta, 2010). The concept of frame-alignment comes from a sub-branch of social movement theory which is known as framing theory. Framing theorists such as Wiktorowitcz focus on “the social production and dissemination of meaning and on how individuals come to conceptualize themselves as a collectivity” (Dalgaard-Nielsen, 2010). A *frame* describes an individual’s worldview, values and beliefs, and frame-alignment refers to the process whereby one reduces the cognitive dissonance between one’s own frame and that of a group. When these two frames are aligned there is resonance between the two parties, and this process explains what makes ideas and beliefs in social movements so powerful.

From this description of frame-alignment it is not clear where it might fit in the IVEE framework. However this does not mean that the social movement theoretical approach conflicts with or is incompatible with IVEE; it simply means that the theory must be approached from a different angle. Recall that IVEE considers causal factors at different levels — the individual, ecological and systemic levels. The problem with a concept such as frame-alignment is that it is not clear at which level it sits, because it is in itself a complex process that works on more than one level. In order to understand whether the insights offered by social movement theory are compatible with IVEE it is necessary to separate out the analysis into different levels.

Renowned political scientist Della Porta has done just this, analysing radicalisation at what she calls the macro, meso and micro levels (Della Porta, 2009). In the course of her research she has examined political violence and extremism in Italy, Germany, the Basque region and Ireland over the 1970s-1990s, and conducted comparative analyses between these groups and with the more modern phenomena of global Islamism. Through this she has identified several key concepts at each level. To what extent can these concepts be synthesised using IVEE?

At the macro level Della Porta proposes two key factors influencing radicalisation: the closing down of political opportunities, and experience of violent interaction on the streets (2009, p. 11). Across a variety of states Della Porta observed that closing down political opportunities has often preceded a rise in political violence. However, this is a situational factor. Recall that Situational Action Theory considers crime as a moral action that comes as a result of a person identifying an act of criminality as an action alternative and then choosing to act on it. Where political opportunities are closed down, this reduces the possible legal action alternatives a person has available, thus making them more likely to choose a criminal action rather than a non-criminal one. In other words, this factor does not at first affect a person's *propensity* for criminal activity, and hence it does not actually form part of the radicalisation process. It does however increase the likelihood that they would choose a criminal action, due to the limited number of options available to them.

The second factor, experience of violence on the streets, builds on the first. If a person, through the limited options available to them, chooses to engage in violent political action, this will have an effect on their environment and their own exposure to criminalising influences. Other people present will also become exposed to that violence, possibly affecting their moral development, as they may be influenced by what they have seen and experienced and consider violence to be morally acceptable. This forms part of the IVEE process in that when violence happens a radicalising setting emerges, and the people who take part or witness that violence become exposed.

At the meso level, Della Porta proposes that three factors are relevant to radicalisation: these are *competitiveness*, *encapsulation*, and *narrative* (2009, pp. 13-15). The first of these, *competitiveness*, is the idea that different groups compete with each other in terms of their methods, with some resorting to far more violent means than others. An individual who supports a cause may have a choice of several groups to associate with; it is likely that they will choose to associate with the group of whose methods they most approve. Looking at this phenomenon using the IVEE framework, an individual in a group that uses peaceful means would not have much exposure (if any) to radicalising moral contexts, while a person associating with a group that often resorts to violence would have plenty. Additionally, a person who already considers violence acceptable according to their own personal moral code would likely be attracted to groups where violence is a normative behaviour, thus becoming further exposed through a self-selective mechanism.

Della Porta's second idea, *encapsulation*, refers to the idea of a group having to go "underground" to escape law enforcement. When this happens, group members become increasingly cut off from the wider world, and therefore from ideas that might challenge them. Some groups examined by Della Porta had to resort to further criminal activity to raise funds as a result of their going underground, such as robberies or kidnappings. Encapsulation therefore creates another situational factor in the SAT model, encouraging group members to engage in criminal activity they otherwise would not. This creates further criminogenic settings, to which group members become further exposed, possibly influencing their moral development, and so the cycle continues.

The idea of the *narrative* is popular among radicalisation scholars, and it links in with the notion of a *terrorist ideology*, which will be explored in greater detail later. According to Della Porta, a narrative provides targets for the group which, in the case of groups supportive of violent methods, enable them to legitimise their violence. However it could be equally argued that the same narrative, when placed before a non-violent activist group supportive of the same beliefs, would not make the group consider violence to become legitimate. It might provide targets for peaceful demonstrations or the writing of angry letters, but it would not on its own encourage previously non-violent activists to change their moral standards and become violent. This argument suggests that narrative is not an inherent part of the radicalisation process as defined in this thesis.

The final level examined by Della Porta is the micro level, and at this level she identifies two concepts: *affective focussing* and *cognitive closure*. Affective focussing concerns the changing of an individual's social network as they become more and more part of a group. In IVEE this relates to the increased exposure to radicalising ideas that a person gets from spending more time with their group. Cognitive closure is where an individual comes to believe the version of reality that the group puts forward, as opposed to the view of reality accepted by the wider public. Again this relates to the increased exposure to radicalising ideas, but cognitive closure further implies that these ideas are actually taking hold and affecting a person's view of the world. In this way a person's moral education becomes determined by those in the group around them, and (unless they are very strong-minded) their views on what is morally acceptable will be affected.

The social movement theoretical approach to understanding radicalisation offers a range of concepts to explain how radicalisation happens. Analysing these concepts through the lens of SAT and IVEE allows us to distinguish between the direct and indirect causes of political violence and of radicalisation, along with gaining an increased understanding of how these concepts interact with each other and the effects they have on the wider person-environment system. The ideas put forward by social movement theory are compatible with both SAT and the IVEE framework, and thus add further credence to their usage in this thesis.

2.3.6 Social Psychological Theories

Social psychology is a sub-discipline of psychology that looks to transactions among groups of people to explain individual behaviour. The field is "an attempt to understand and explain how the thought, feeling and behavior of individuals are influenced by the actual, imagined or implied presence of others" (Mitchell, 2010, p. 246). Its relevance to the study of radicalisation comes from the observation that terrorism is more often than not a group phenomenon — for instance Post (2005) has observed that it takes a charismatic leader and a group culture of martyrdom to inspire people to commit suicide attacks. Psychologists who criticise the social psychological approach such as Taylor (2010) consider the field to be too concerned with "propensities to commit violence or their presumed social context" instead of concentrating on actual violence, however as this thesis is focussed on the development of an individual's propensity, the criticism is irrelevant here. It is also worth noting that even researchers in the field of lone-actor terrorism concede that they are seldom entirely socially isolated, and often influenced by a wider group or social movement (Gill et al., 2014). The potential importance of social psychology in radicalisation thus deserves some attention.

This section considers some mechanisms explaining radicalisation that have emerged from the social psychological school, and examines to what extent the IVEE framework can be used to synthesise these ideas.

There are a number of key tenets in social psychology that can been applied to radicalisation. The tenets of particular relevance are:

- Group contexts cultivate extreme attitudes;
- Group decision making is more biased and less rational than individual decision making;
- In-group/out-group bias, where the behaviour of those within the group is treated more positively than that of outsiders;
- Decreased sense of individual responsibility for actions;
- Perceived incentives and rewards of group membership, such as social affiliation or a personal sense of meaning;
- Group internal norms and rules that control member behaviour (Borum, 2011a).

The background to many of these phenomena has already been made clear through Della Porta's work on the relevance of social movement theory to radicalisation. But what more can these phenomena tell us about the mechanisms within the radicalisation process? McCauley and Moskalenko have suggested five mechanisms they believe to be responsible for group radicalisation, which are inspired by these social psychological tenets. These are:

- Group polarisation: extremity shift in like-minded groups;
- The multiplier: extreme cohesion under isolation and threat;
- Outbidding: competition for the same base of support;
- Condensation: competition with state power;

- Fissioning: within-group competition (McCauley and Moskalenko, 2008, p. 418).

Again there is some similarity with the mechanisms suggested by Della Porta of the social movement school. However, recall that radicalisation is the development of an *individual's* propensity to commit acts of terrorism. Groups do not commit terrorist attacks — individuals do. So how do these group mechanisms affect the state of mind and sense of morality of individual group members? We can turn to McCauley and Moskalenko (2008) again to answer this question, as they have also produced a set of individual radicalisation mechanisms:

- Individual radicalisation by personal victimisation;
- Individual radicalisation by political grievance;
- Joining a radical group — the "slippery slope";
- Joining a radical group — the "power of love" (McCauley and Moskalenko, 2008).

Taking these in turn: individual radicalisation by personal victimisation is "a path much cited in explanations of suicide terrorists" (McCauley and Moskalenko, 2008, p. 418), for instance in the case of the suicide branches of the Tamil Tigers who were described as the survivors of Sinhalese atrocities. Data is scarce, but the social psychological view is that personal victimisation is unlikely to account for group sacrifice unless a process of frame alignment has taken place. As discussed above, frame alignment is a concept that works on a number of levels and is difficult to express in terms of IVEE. In terms of personal victimisation, the IVEE interpretation would be that an individual's sense of morality changes through their experience of being victimised, and they may come to see revenge as a morally justifiable action. When such people then have exposure to others who share their personal grievance and contemplate revenge, this strengthens their sense of the justification of their cause, making them more likely to take violent action.

Individual radicalisation by political grievance describes what happens when an individual acts alone (the "lone wolf" terrorist) in response to a political trend or event. McCauley and Moskalenko suggest that for this type of radicalisation more than others, "there is a probability of some degree of psychopathology" (2008, p. 419), a view supported by Corner and Gill (2015) in their research showing the higher prevalence of mental illness among lone-actor terrorists when compared with terrorists who act as part of a group. From an IVEE perspective, this suggests that radicalisation of this type occurs among people who have a very high level of cognitive susceptibility to radicalisation, and require relatively little exposure to radicalising influences to develop the propensity to commit a terrorist act. According to our definition of terrorism some form of cause is still needed, however, in order to distinguish these individuals as terrorists rather than general criminals, and this comes from the political grievance.

The "slippery slope" returns to the idea of the conveyor belt which, although generally regarded as an unhelpful metaphor, does still apply in some cases. The "slippery slope" follows the principle that if an individual considers one act to be acceptable, and the rest of his/her peer group consider a slightly more extreme act to be acceptable, that the individual will come to accept the position of the group. This process then continues and escalates. It is easy to explain this idea in the language of IVEE, as it simply sees an individual with one view of morality gain exposure to people with a slightly different view, and this affects the moral education of the individual.

The "power of love" idea is more related to social network theory, which will be examined in more detail later. Suffice to say at this point that when an individual joins a group they develop a social attachment to the other people in the group. This attachment gives those people a high degree of influence over the individual, and as a result the individual may act counter to their actual beliefs because of the strength of the bonds they have with members of the group. This mechanism works at the situational level rather than the developmental level, and therefore does not constitute "radicalisation" as defined in this thesis. However the "power of love" may act in conjunction with the "slippery slope" as a way of changing an individual's sense of morality after they have taken part in an activity.

Borum (2011a) adds two more mechanisms to this list: individual radicalisation in status and thrill seeking, and individual opening to radicalisation (or "unfreezing"). Both relate to the reasons why an individual may choose to join an extreme group — either due to the perceived excitement of being involved, or due to some destabilising life event. In the language of IVEE, these are reasons why an individual chooses to become exposed to a radicalising narrative in the first place.

This section has examined the theories put forward by social psychologists as to how and why radicalisation happens. The suggested radicalisation mechanisms can all be reformulated in terms of IVEE and support it as a theoretical framework. It is worth noting that the social psychological mechanisms all tap into either the individual vulnerability or exposure parts of IVEE, with no consideration given to the systemic level (emergence). This supports this thesis' decision to use IVEE as the theoretical framework on which to build, as it presents the most general and all encompassing theory of radicalisation currently in existence.

2.3.7 Conversion Theories

Conversion is a word that refers to an individual acquiring a new religion, but there are some aspects of how this happens that are also applicable to radicalisation. Much has been written about conversion in the sociological and psychological literature over the past few decades, making it a rich body of research on which to draw (Borum, 2011a, p. 22).

Of this research, the "developmental" or "stage" model has generally been the most popular approach — much like the multi-stage radicalisation processes discussed in Section 2.3.4. However the linear approach taken by these models was overly simplistic, and they were ultimately superceded when Rambo (1993) introduced a model comprising seven components, which is more cumulative and allows each component to recursively affect the others. These components are:

- Context: the field of cultural, historical, political or social factors that either impede or speed up the conversion;

- Crisis: a state of disequilibrium, usually caused by personal or social disruption;
- Quest: a process of seeking solutions to restore equilibrium, often precipitated by a crisis;
- Encounter: the initial contact between the seeker and the proponent of a spiritual option;
- Interaction: exchanges between the seeker and proponent;
- Commitment: a decision to invest in the new religion, accompanied by a promised bond to identify the person as part of the movement;
- Consequences: the effects of the actions and decisions made in service of the belief, constantly monitored and evaluated (Rambo, 1993).

There are similarities between this conversion model and the radicalisation process put forward by Wiktorowitcz (2005), and indeed it is similarly simple to determine how each component fits into IVEE. *Context* affects the environment, including both emergence and selection; a *crisis* makes a person more cognitively vulnerable; a *quest* increases the likelihood that they self-select to expose themselves to a converting (or radicalising) influence; an *encounter* is the start of this exposure; and *interaction* leads to an increase in exposure. *Commitment* represents the individual's conscious decision to become part of the movement, and therefore in the case of terrorist movements it is the culmination of the radicalisation process: once a person has officially committed in their own minds, they have developed the propensity to act as the terrorist group wishes them to act. The *consequences* component of Rambo's model is then part of the situational action process — that is, whether a person actually chooses to take a certain action when in a certain situation.

Other approaches to understanding conversion include that of Kilbourne and Richardson (1989), who noted that conversion theories can be divided into two categories: passive and active. The passive theory of conversion sees the convert as a passive target whose will is overpowered by brainwashing. The active theory considers the convert to be a rational actor who seeks out the movement and joins of their own volition. These two types of theory are as equally applicable to radicalisation as they are to religious conversion but, as Kilbourne and Richardson found in the case of religious conversion, the majority of research evidence supports the active theory over the passive one. Interestingly, however, both the active and the passive schools can be synthesised using IVEE, as they simply describe different people and different situations. A passive radicalisation (or conversion) would come about as a result of the individual being highly receptive to new ideas, so that very little exposure is required for them to then become sufficiently influenced that they integrate themselves with the group, receive more exposure, and ultimately become indoctrinated. Active radicalisation is of course similar, in that it requires both individual vulnerability and exposure, but one would expect to see greater emphasis on selection and exposure than on cognitive vulnerability.

Another side of radicalisation that has received greater media attention in recent years is self-radicalisation; that is, radicalisation over the internet with seemingly no personal contact. This is another area where conversion theory has the upper hand in terms of previous research conducted, even from before the era of the internet (Borum, 2011a, p. 24). Lofland and Skonovd (1981) observed that someone considering a new path will undertake their own research into it first, by reading books, watching television, or (more recently) searching the internet for relevant material. They add that "in the course of such reconnaissance, some individuals convert themselves in isolation from any interaction with devotees of the respective religion" (Lofland and Skonovd, 1981, p. 376). This phenomenon can be described in IVEE terms by the individual having immersed themselves sufficiently in the available material (i.e. gained enough exposure), and having sufficient initial cognitive susceptibility that personal connections are not necessary to complete their conversion (or radicalisation).

In summary, there are several strands of research into religious conversions that resonate with radicalisation, and some theories that are almost entirely directly transferable. The two fields are not identical, however, with the key difference being that during radicalisation the individual experiences a change in their morality, whereby they end up considering criminal actions to be morally acceptable, when they would not have thought so before. While this holds true for a small minority of religious cults, such as the Solar Temple that promoted mass suicide among its followers (Hall et al., 2000), for the vast majority of religious conversions the moral code promoted by the religion remains compatible with the law, making substantial change to an individual's personal moral code unnecessary. However where similarities between religious conversion and radicalisation do occur, the theories presented are easily synthesised using IVEE, therefore lending further support to its use as the theoretical framework on which this thesis relies.

2.3.8 Social Network Theory

Social network theory regards society as a structure consisting of person-to-person linkages. A social network model is a diagrammatic representation of all the ties between the different actors, which is often written as a graph (Crossett and Spitaletta, 2010). The nodes of the graph frequently represent individuals, but can also be organisations or other entities; the graph's edges represent the relationships between different actors, which in a simple model might purely indicate acquaintance, but a more complex model could differentiate between positive and negative relationships and give an indication of each relationship's strength (Wasserman and Faust, 1994). When applied to radicalisation, social network analysis can provide an indication of who the most influential individuals in a social network are; all individuals linked to the key influencer would then be considered most at risk of being radicalised.

One of the primary proponents of social network theory in relation to radicalisation research is Marc Sageman (2004), who examined two case studies in particular: that of the Hamburg cell who were responsible for 9/11, and the Montreal cell who sought to bomb Los Angeles International Airport in 1999. For both these cells Sageman observed that the groups developed from the bottom up, starting out as just a "bunch of guys" who felt alienated in the societies in which they lived, who then began to develop an interest in jihad after a chance encounter with a radicalised individual.

From an IVEE perspective it is clear that the social network approach emphasises the importance of exposure to radicalising moral contexts. In particular social network theory emphasises the nuances in the exposure element of the IVEE framework, as it highlights that it is not just the amount of exposure an individual has to radicalising ideas, but also the quality of the exposure, as a radicalising narrative will have more impact when it comes from a person the individual trusts and respects than it would from a stranger or a person whose opinion the individual disregards.

Social network theory also offers some interesting insight into the different likely trajectories of differently structured groups. For example Crossett and Spitaletta (2010) compared the Egyptian Islamist groups Egyptian Islamic Jihad (EIJ) and Egyptian Islamic Group (EIG). EIJ's leadership is intolerant of dissent and ensures that EIJ is highly compartmentalised. This makes the movement less vulnerable to interdiction, and also limits the flow of ideas and opinions across the group as a whole. This compartmentalisation therefore forces the disparate cells within the EIJ to experience encapsulation (to use a term from Della Porta's social movement work) and thus the individuals in each cell only gain exposure to the ideas of the others in the cell and those of EIJ's leadership. EIG, on the other hand, favours a much larger network that is open to recruitment and expansion. EIJ are a proscribed terrorist group thought to be responsible for attempting to assassinate Egypt's former president Hosni Mubarak and interior minister Hassan Al Alfi, while EIG have openly criticised Al Qa'ida's violent interpretation of jihad (Kamolnick, 2013). While these differences are unlikely to have arisen solely because of the groups' structures, it is a hypothesis that merits further investigation.

Social network theory has its advocates and clearly can add some interesting contributions to the field. However it is limited in its scope, examining only the exposure strand of the IVEE framework. While individual factors are still acknowledged as having an impact on radicalisation, "[s]ocial network theory considers the attributes of individuals less important than their relationships and ties with other actors within the network" (Crossett and Spitaletta, 2010, p. 16). O'Duffy (2008) also criticises social network analysis's narrow view for ignoring macro-level factors such as social policies that alienate minorities, causing them to develop grievances. IVEE is far wider in scope, incorporating the impact of grievances through selection mechanisms that cause a person to become more likely to seek out radicalising settings, while also giving weight to individual cognitive factors.

2.3.9 The Role Of Ideology

One cannot listen to news reports of terrorist attacks without hearing the term "ideology" frequently used in relation to why an attack has happened. But it is important to note that the way the term is used in the media is not necessarily the same as the way it is used in academia. Among scholars, ideology is a term that was much debated during the 1960s in the sociological and political science arenas in relation to certain political schools of thought, such as the "Soviet ideology" (Minar, 1961; Putnam, 1971; Huaco, 1971). Other academic fields emphasise certain nuances of the term, leading to disputes within disciplines: for instance, a social anthropologist might interpret "ideology" to be "a part of culture concerned with a representation of the social and a commitment to central values", while another may use a definition of ideology inspired by Marxism which considers ideology to be an explanation for why workers are willing to be exploited by a capitalist minority (Barnard and Spencer, 2010). Away from academia, journalists and politicians using the word "ideology" do not specify their meaning, but one assumes that most intend a dictionary definition such as "the set of beliefs characteristic of a social group or individual" (Oxford, 1999).

Such a range of meanings is one reason for avoiding using the word "ideology" altogether — as with all terminology, ideology is only a helpful notion if it is well defined. However, the terms "terrorism" and "radicalisation" can be similarly criticised for having a wide range of meanings, but this does not prevent this thesis using them (though ensuring that they are properly defined first). It follows that if a case can be made for ideology's importance in the radicalisation process, the term should be incorporated.

From the literature review above, ideology has only been specifically mentioned as a part of Silber and Bhatt's four stage process (see Section 2.3.4). It is worth noting that the authors of this paper are practitioners, not academics. Silber and Bhatt place great emphasis on the importance of the jihadi-Salafi ideology in radicalisation, noting that it is "the driver" that motivates people to carry out acts of terrorism such as the Madrid 2004 bombings and London's 7/7 bombing. Silber and Bhatt do not define what they mean by ideology, but they state that the jihadi-Salafi ideology is underpinned by the writings of Sayyid Qutb in the 1960s, who believed that Islam was under attack from the West and that militant jihad could be used to attack institutions and societies to overthrow non-Islamic governments (2007, p. 19).

What Silber and Bhatt are essentially describing is the Islamist narrative. Narrative is a concept that was discussed in Section 2.3.5 with regard to social movement theory; it is more rigid and better defined that ideology, referring as it does to the message put across by terrorist recruiters justifying an individual to take action (Della Porta, 2009). However, as explained in Section 2.3.5, when a narrative is placed in front of non-radicalised individuals, it does not of its own accord lead those individuals to want to commit terrorist attacks, and therefore it does not in itself cause radicalisation.

However an alternative argument in favour of the importance of ideology in the radicalisation process is connected to the idea of moral shocks, discussed in Section 2.3.1. The argument is that when someone hears the ideology (by which we mean narrative), this inspires them to join an activist group in the same way as a moral shock would. That activist group may be peaceful and law-abiding, in which case one would not expect radicalisation to occur. Or the activist group may have radicalised individuals among its members, in which case radicalisation may occur due to the non-radicalised group members becoming exposed to a radicalising moral context. The point however is that the only role of the ideology (or narrative) is that it inspires an individual to join a group; it is the moral education that they then receive once in the group that influences whether or not they develop the propensity to become radicalised.

A further anecdotal case against the relevance of ideology in radicalisation comes from one of the attacks cited by Silber and Bhatt as being driven by ideology: the 2004 Madrid bombings. Terrorists associated with Al Qa'ida attacked Madrid on 11th March 2004 because, they claimed, they opposed Spain's stance on the war in Iraq. Three days later Spain had voted in a new government, who announced that they intended to withdraw their troops from Iraq as soon as possible, thus meeting the demands of the terrorists. But despite this, on 2nd April 2004 another bomb was found and a police raid on the terrorist cell the following day uncovered intent to carry out further attacks (Wilner and Dubouloz, 2010). This evidence of the terrorist cell having the capability and intent to conduct further attacks on the Spanish population suggests that the reason given by the terrorist cell for the original attack was untrue; it may have been the initial "hook" to get them started on the road to radicalisation, but after they had been radicalised the ideology itself was no longer important.

To summarise, the role that ideology plays in radicalisation is restricted to the effects that extremist narratives can have. A narrative can act in the same way as a moral shock, giving an individual a reason to involve themselves in a particular cause, which then may increase the likelihood that they become exposed to radicalising moral contexts. However the narrative itself does not cause radicalisation, and so we conclude that "ideology" is *not* a part of the radicalisation process. It is therefore not a relevant concept for this thesis.

2.4 Conclusion

Since 11th September 2001, social researchers and practitioners together have produced a plethora of literature seeking to answer the question of what the radicalisation process looks like. Much of this research has centred around a number of social theories that have been explored in the course of this chapter. Using a definition of radicalisation as the development of an individual's propensity to commit acts of terrorism, this chapter has introduced the IVEE theoretical framework for radicalisation developed by Bouhana and Wikström (2011), and considered how the theories suggested by the literature can be synthesised using this framework.

2.4.1 Strengths and Weaknesses of IVEE

IVEE goes some way to explaining the causal mechanisms behind an individual developing the propensity to commit acts of terrorism, but it is not the only way to express the causes of radicalisation as a theoretical framework, and several others were explored over the course of the radicalisation literature review. However one of the great strengths of IVEE is that while it is a *theoretical* framework, it has been developed from the bottom up from multiple empirical studies and thus it has considerable empirical validity (Bouhana and Wikström, 2011). The framework is flexible and allows for causal factors across the individual, ecological and systemic levels to interact, explaining how these interactions ultimately lead to a change in propensity. It can therefore be used to synthesise the existing theoretical and empirical knowledge-base across these three levels, as demonstrated over the previous sections.

However there are some areas where IVEE lacks clarity, in particular concerning emergence. Of all the levels in IVEE emergence is the least well-researched, and so the number of sources upon which the framework relies is considerably smaller for emergence than for individual vulnerability or exposure. The work conducted by Sampson (2004, 2009) provides some background to the heterogeneity of geographical locations by introducing the concept of collective efficacy, but there are other aspects of geography which the framework ignores — most notably, the role of the road network and other infrastructure, and the use of land. Previous research has determined that such geographical features do have a role to play in crime patterns (see for example, Bowers (2014)), and it is entirely plausible that they have a causal effect in the propensity development process in addition to the situational action process. However, although the IVEE framework does not currently make provisions for the potential importance of such geographical features in the radicalisation process, with further work it could be extended to incorporate them. In their paper describing the framework Bouhana and Wikström admit that while it is key to the process, "the understanding of emergence is underdeveloped" and further research is required.

2.4.2 Radicalisation Versus Criminal Propensity Development

The IVEE framework for radicalisation uses the assumption that there is no fundamental difference between the process of radicalisation and the process by which propensity for crime more generally develops. However Section 2.1.1.2 stated that the only difference between an act of terrorism and an act of crime is in how the offender's criminal (or terrorist) propensity has developed. This raises a question over whether the assumption upon which IVEE relies is reasonable. So can we determine what actually *is* the difference between radicalisation and more general criminal propensity development?

There appear to be three areas where an argument could be made for radicalisation being markedly different from the way that an individual's propensity to undertake criminal activity more generally develops. These are in the types of crime the individual might ultimately commit, the level of morality required for an individual to consider such acts to be action alternatives, and the rarity of radicalising moral contexts when compared with general criminogenic contexts.

2.4.2.1 Type of crime

As already discussed, the term “crime” covers a wide spectrum of activities, from shop-lifting to mass fraud, and from parking infractions to murder. While the term “terrorism” could technically include any activity that is a criminal offence, one is more likely to associate the word with the intent to kill or cause significant damage to property. Indeed, taking homicide as an example, it is a very rare crime in general — in England and Wales there were only 515 homicides out of over three million victim-based crimes for the year 2014, which is a rate of 0.02% (Office for National Statistics, 2015). According to the Global Terrorism Database (2015) there were 712 incidents branded “terrorism” in United Kingdom between 2000 and 2014, of which 32 have resulted in fatalities — a rate of 4.5%. While the comparison is not perfect, the difference between the two percentages strongly suggests that terrorist offences are more likely to consist of homicide. Similar comparisons can be made for crimes related to property damage.

At the other end of the spectrum, one does not expect crimes such as parking infringements or burglary to be regarded as terrorism. However, in certain circumstances they might be: for instance, someone planting a car bomb may park on a double yellow line, and someone intending to make their own explosive may steal fertiliser from a farm. But for incidents such as these, the relatively minor crime (parking infringement or burglary) is part of a bigger plot that includes a more serious crime. From the perspective of the individual’s propensity for crime, even if they are simply caught stealing fertiliser, for this to count as being part of a terrorist plot there would have to be evidence that they had intent (and therefore the propensity) to carry out a far more serious crime.

It is therefore proposed that one difference between radicalisation and the development of an individual’s propensity to conduct other criminal acts is that the individual must have developed the propensity to commit a severe crime such as homicide or significant property damage.

2.4.2.2 Level of morality required

This distinction between types of crime is all very well, but there are still plenty of instances of homicide and property damage that are not considered to be linked to terrorism. In order to fully differentiate between homicide or property damage attributed to terrorism and that associated with general crime, it is necessary to return to Victoroff's definition of terrorism (discussed in Section 2.1.1.2). One of Victoroff's principles was that a terrorist action is intended to influence and change the behaviour of a target audience using methods of fear among non-combatants. Does this distinction translate into a difference between what it means for someone to have the propensity to commit acts of terrorism versus a general act of crime?

Recall that according to Wikström an individual's criminal propensity consists of two attributes: an individual's morality and their ability to exercise self-control. However the contribution of these two attributes to an individual's criminal propensity is not necessarily a simple one. For example, if an individual's level of morality is such that they consider acts regarded by most as highly unethical to be perfectly acceptable, then even if this individual did exercise self-control this would not stop them committing crimes. Their ability to exercise self-control would thus be immaterial. However an individual with a strong sense of morality but only a weak capacity to exercise self-control would be more tempted to commit a criminal act on an impulse than an individual of the same morality with better self-control. Some crimes are considered to be more likely the result of an impulse than others — in particular violent crimes including homicide (Gottfredson and Hirschi, 1990). But a homicide committed on an impulse would be regarded as a crime unrelated to terrorism, as there would be no intent to influence a target audience as a result of the act.

This raises the idea that a significant amount of premeditation is necessary for terrorism, and therefore that an individual intending to carry out an act of terrorism would require a certain level of morality regardless of their ability to exercise self-control. Can it therefore be argued that capacity to exercise self-control is completely irrelevant to radicalisation? If self-control only had an impact on behaviour at the situational level this might be the case. However, as the interconnectedness of the levels in the IVEE framework illustrates, propensity development is a recursive process. An individual with weak capacity to exercise self-control but a higher sense of morality may, impulsively, take part in an activity they consider to be unethical. At this point they may regret their action and amend their behaviour according, or alternatively they may change their view of the ethicality of their action — thus affecting their moral education (Gino et al., 2011). They may as a result have fewer qualms about repeating the activity, or even regard other activities previously considered unethical to now be acceptable to them. Thus, a weak capacity to exercise self-control can still contribute to radicalisation, by making an individual more likely to become exposed to radicalising moral contexts.

In conclusion, for general crime (as previously discussed) an individual's criminal propensity comprises their ability to exercise self-control and their level of morality. However, it is proposed that for an individual to count as "radicalised" they must have a certain "level" of morality, regardless of their capacity to exercise self-control. While their levels of self-control may play a role in *how* the person comes to be radicalised, it is suggested that low capacity to exercise self-control is not necessary in a radicalised individual.

2.4.2.3 Rarity of radicalising moral contexts

Criminogenic moral contexts can be found all over the UK. They include such diverse locations as nightclubs where people take recreational drugs, a park popular with adolescents, or even the Houses of Parliament during the MP's expenses scandal. However radicalising moral contexts are far harder to find. Even settings that might at a first glance be thought of as radicalising, such as a street corner where someone is handing out leaflets promoting an Islamist narrative, are not in themselves radicalising. As already discussed, a narrative or a moral shock might inspire an individual to develop an interest in joining a movement, but it does not in itself radicalise people. In order to find a radicalising moral context in the UK a person has to actually seek them out — they have to join a covert group advocating violent action, or search the internet for websites posted by people who are already radicalised.

The rarity of radicalising moral contexts in UK society when compared with criminogenic moral contexts presents a significant difference between the two processes of propensity development. For radicalisation, as most individuals would have to actively seek out a radicalising moral context, selection mechanisms play a far greater role than they do for general criminal propensity development, which many people happen across on a relatively regular basis.

In the IVEE framework selection mechanisms were separated into individual selection (or *self-selection*) and selection that is due to social or demographic factors. Self-selection is determined by individual lifestyle preferences, while social selection dictates the locations that certain groups are more likely to frequent — for example, local community centres or youth clubs favoured by people from a particular ethnic or religious background. The greater importance of selection mechanisms in radicalisation (as opposed to general criminal propensity development) thus makes the influence of socio-demographics all the greater, and goes some way to explaining why certain groups have been more prevalent in terrorist organisations — Irish Catholics or 2^{nd} generation South Asian Muslims, for example — while people across all sectors of society commit crime.

It is therefore proposed that the rarity of radicalising moral contexts in UK society, and the resulting heightened importance of selection mechanisms in the radicalisation process, are a key difference between the development of an individual's criminality and radicalisation. This does, however, raise the question of how — if at all — the radicalisation process would be affected if the prevalence of radicalising moral contexts were to increase significantly.

2.4.3 Primary Research Question

In this chapter the literature has been explored in such as way as to enable comparisons to be drawn between how a person's propensity to commit general acts of crime develops, and the radicalisation process. The key differences between the two have been identified as the severity of the crimes, the level of morality required of a radicalised individual, and the rarity of radicalising moral contexts. However, each of these factors lie on a spectrum, with a significant grey area in the middle. Is planting a hoax bomb sufficiently severe to count as terrorism, if the offender never intends to cause any physical damage or harm? How about the offender who is radicalised enough to store equipment for a terrorist attack, but who still considers taking life themselves to be morally wrong? And what would happen if the prevalence of radicalising moral contexts in the UK were to increase significantly, as it has in parts of Syria and Iraq in recent years?

The IVEE framework relies on the assumption that there is an equivalence between the radicalisation and criminality development processes. If this assumption holds, the extensive literature on the development of criminal propensity can be used to augment our far more limited knowledge about radicalisation. It is therefore the intention of this thesis to test this assumption and determine whether there is really a difference between the development of criminality and radicalisation. It will do this by answering the research question: are the radicalisation and criminality development processes indistinguishable?

Chapter 3

Methodology

At the end of Chapter 2 the primary research question was presented; in this chapter we consider how best it can be answered. The first section of the chapter examines what further research questions arise as an immediate consequence of the primary research question and considers potential approaches to tackling them. The second section looks in particular at the method of mathematical modelling, questioning whether the criminality development and radicalisation processes can be modelled effectively and if so how it could be done. The third section presents an overview of the research design and establishes its validity, then finally the chapter ends with a short section on ethical considerations.

3.1 Further Research Questions

As stated at the end of the previous chapter, the primary research question to be answered by this thesis concerns whether there really are any fundamental differences between the process by which an individual develops the propensity to commit crime, and radicalisation. In order to answer this it is first necessary to answer the question of what are the individual, environmental and systemic factors that contribute to the radicalisation and criminality development processes. This question has partially been answered by the IVEE framework and the literature examined in Chapter 2, but there remain many unknowns which need to be determined before we have enough information about both processes to be able to compare them.

The IVEE framework itself provides a means of grouping these unknowns into sub-questions to be addressed in order for the primary research question to be answered. These sub-questions are as follows:

- On selection mechanisms:
  - What attributes of a person cause them to have a preference for certain settings over others?
  - What attributes of a setting attract or deter people from visiting?
- On the emergence of criminogenic or radicalising settings:
  - To what extent does the presence of criminally-minded or radicalised people at a setting cause it to become criminogenic or radicalising?
  - What environmental factors affect how likely a setting is to become criminogenic or radicalising?
- On exposure to criminogenic or radicalising moral contexts:
  - What psychological characteristics cause a person to be more easily influenced by any criminogenic or radicalising moral contexts to which they become exposed?

Many if not all of these individual sub-questions can be answered by existing research conducted by social scientists or psychologists. However even if all the individual questions can be answered this way, the research question as a whole cannot be in its entirety. As the previous chapter explained, the processes of criminality development and radicalisation form a part of a wider socio-ecological system, and understanding and predicting the behaviour of processes within that system is extremely difficult. Answering the research question using conventional social science methods alone would require a large number of cases to be studied in depth over a significant period in order to allow the effects of seemingly random factors to be averaged out. The resources required before such a study would start yielding even the most tenuous of results would be considerable, and by the time results are being produced the social system may have altered.

However this does not mean that the research question cannot be answered; it simply means that it may have to be done in an unconventional way and draw on techniques from disciplines outside the social sciences. A starting point for where we can turn for an appropriate methodological approach comes from the 18th century philosopher David Hume's 1739 work "A Treatise of Human Nature". In this Hume considers the ideas of cause and effect extensively, arguing that "whatever has a beginning has also a cause of existence", but he concedes that for effects dependent upon "an intricate machinery or secret structure of parts" that "we make no difficulty in attributing all our knowledge of it to experience", giving the example that no-one would assert that they can give the ultimate reason as to why milk or bread are nourishing for men but not for lions or tigers (Bailey, 2004, p. 167). What Hume is describing here is the difficulty of understanding causality when the causal relations are within a system which is itself poorly understood or multifaceted, meaning that such knowledge would simply be put down to "experience" because those causal relations could not be determined. However science and human knowledge have advanced considerably since then.

A good example of the progress made in determining causal relations in a system that Hume would have counted as "an intricate machinery" comes from weather forecasting. Weather forecasters for centuries have understood the basic causal mechanisms within weather systems: for instance that the build-up of certain types of cloud causes rain, or that high pressure suggests stability in weather for a time. But despite understanding the individual interactions of the component parts in a weather system it is very difficult to predict what will happen further than a few days into the future because there are too many unknowns and too much uncertainty in the system. Modern weather forecasters have combatted this problem through using computer simulations to establish how weather is likely to develop given what we know about the weather at a particular moment in time and the causal mechanisms that lead to change (Met Office, 2015).

Weather forecasting is an example of a complex system. Understanding how one part of a complex system behaves is not enough to allow the behaviour of the whole system to be predicted — to do that we need to understand *every* causal relationship in the system and how each component part interacts with each other. Human social systems can be extremely complex, as the process by which people become radicalised or develop the propensity for crime described in Chapter 2 shows. The mathematical modelling approach adopted by modern weather forecasters may provide a way to turn that complexity into something understandable, and enable the primary research question to be answered.

3.2 Mathematical Modelling

3.2.1 Modelling Social Systems: A Brief History

A "model" is simply a representation of the real world. The term "mathematical model" is used when a real world problem is turned into an abstract mathematical problem that is intended to approximately replicate the original (Clapham, 1996). Mathematical modelling techniques have been in use for centuries and have sought to replicate many different aspects of everyday life. One of the simplest and oldest examples is a map, which is essentially a model depicting three dimensional terrain as a two dimensional diagram. More obviously mathematical examples still date back several centuries: for example in the late 17th century physical scientists used Newton's laws to better understand and predict physical phenomena. Even in the social sciences mathematical modelling has a long history: Adam Smith's 1776 treatise "The Wealth of Nations" gave birth to modern economics, a field that seeks to use mathematical rules to explain and predict production and consumption in society.

However economists have long been accused that their models suffer from a lack of realism due to them relying on overly simplistic assumptions about social behaviour (Gintis, 2009). While more recent economic models are more sophisticated than before, they were still unable to predict large events such as the 2008 economic crisis, with reasons cited including a lack of ability to model hierarchical networks of interdependency and herding behaviour (Ball, 2012, p. 33). With the benefit of hindsight today's economic modellers are making up for the failures of the past; considerable progress is now being made towards constructing models able to predict stock market crashes (Sornette et al., 2015), and more focus than ever before is being put on multi-disciplinary research such as econophysics in order to achieve this (McCauley et al., 2016).

Econophysicists McCauley et al. observed that economic systems are "complex organizations of interacting adaptive agents whose interconnections with institutions can generate unexpected patterns, feedback loops, and diffusion processes". The same can be said of other aspects of the social world, leading some social scientists to question whether social systems are so complex that they cannot be modelled at all with sufficient accuracy for them to be of any use. However with increasing multi-disciplinary interest in how physical science techniques can be used to formalise social science theories such as rational choice and the impact of cultural norms, a formalised analytical core for sociology is now starting to develop (see, for example, Gintis and Helbing (2015)), making complex social models more grounded in theory. And as modelling techniques have developed and technology improved, systems that would never have been possible to model a few decades ago are now providing guidance to policy-makers in a variety of fields such as traffic management and public health (Keeling and Rohani, 2008; Ball, 2012).

Models vary according to their purpose. Some models are designed to classify datasets into classes — for example dividing a population into socio-demographic groups as an aid to predicting voting patterns. Classification algorithms have developed in complexity over the decades, with techniques such as neural networks and decisions trees forming a key component of artificial intelligence (Gahegan and West, 1998). However the only role of these models is classification; they can neither explain a cause nor predict a future outcome. In order to do that a model needs to describe the *relationships* between the different variables.

Some models simply describe direct relationships, while others involve a number of entities that interact with each other in different ways. Sometimes a simple model is enough, even for something as seemingly complex as human behaviour. An example would be the relationship between the daily maximum temperature in a location and the number of ice creams people in that location purchase on a given day. By collecting data covering a sufficiently long period of time, this data can be used to conduct a statistical analysis and then create an equation allowing us to predict how many ice creams are likely to be purchased given the temperature on a particular day. However, for complex systems involving multiple variables with inter-dependencies it is not possible to predict an outcome using just one equation, and instead a simulation must be used (Gilbert and Troitzsch, 1999, p. 16).

A simulation is a specific type of model. In the same way as the basic statistical model used to predict sales of ice creams has an input (in this case temperature) and an output (the predicted number of ice creams), simulation models also have inputs and outputs. However the difference between simulation and other types of models is that a simulation model can be "run forward" through (simulated) time to allow the researcher to observe its behaviour at some point in the future (Gilbert and Troitzsch, 1999, p. 16). The quality of the simulation can then be assessed by comparing its behaviour with that of the real world system it is trying to replicate. Simulations are particularly appropriate for modelling non-linear systems where analytical reasoning would be very difficult or even impossible; human social systems that are complex in nature would therefore best be modelled with a simulation.

Simulation models are often also referred to as "computer simulations", because the calculations conducted by the simulation are generally extensive and are far more easily done by a computer than by hand. For this reason the development of simulation as method has largely mirrored the development of computer processing power. The earliest social simulations originated in the 1960s, and include queuing models and models that calculate how long it takes an emergency vehicle to get to an incident. In 1971 Schelling developed a simulation of social segregation with no computing power whatsoever; this influential paper illustrated that stark patterns of racial segregation emerge when individuals have only a slight preference for living among those of the same race, and demonstrated "the dynamic relationship between individual behavior and collective results". While computationally simple, the simulation produced by Schelling was sophisticated enough to incorporate heterogeneity across the agents in the model and introduces the concept of a tipping point — where a minority gets sufficiently large that the majority decide to leave the area and the minority takes over.

Many of these early simulations suffered from being over-ambitious and relied heavily on quantitative assumptions that were backed by very little evidence, leading to the simulations producing unreliable results and the entire credibility of simulation as method being questioned (Gilbert and Troitzsch, 1999, p. 6). However, 50 years later simulation models have been developed that are actively assisting policy-makers in fields as varied as climate change, migration, and the influence of social media (Ball, 2012).

3.2.2 Simulation Models for the Study of Crime

Crime science and criminology have been relatively late adopters of the use of simulation models when compared with other social science disciplines (Brantingham and Brantingham, 2004). However simulation models have an enormous amount to offer the field. As has previously been noted, the analysis of the causes of crime requires understanding extremely complex socio-ecological systems, and traditional research methods are resource-intensive, expensive and time-consuming due to the level of detail required in the data and the longevity of interventions, while conducting actual experiments raises significant ethical concerns (Groff and Birks, 2008; Johnson, 2009). Simulation provides a solution to all these issues, as the effects of different interventions in different environments can quickly and cheaply be tested *in silico*. It also provides an easy means of comparing different implementations of an intervention to determine, for example, whether rolling an intervention out quickly is significantly more effective than rolling it out over the course of a year

(Johnson, 2009). Simulation can also give an indication of the "dosage" of an intervention required for a desired effect to be achieved (ibid).

A further benefit that simulation offers crime science researchers is a means of providing generative explanations for phenomena (Epstein, 1999; Eck and Lui, 2008; Birks et al., 2012). A simulation comprises a set of rules and a set of inputs; if a phenomenon emerges from one set of rules and inputs but not from another, the researcher can draw conclusions as to what variables are required to generate the phenomenon. Limitations with simulations remain however; for instance an artificially generated phenomenon can demonstrate the *sufficiency* of the variables in generating that phenomenon, but not the *necessity*: alternative rules and inputs could generate the same phenomenon (Eck and Lui, 2008, p. 203). Additionally, as is the case with other fields, a simulation model can only be as good as the data that is used in its development (which will be discussed further in Section 3.2.4) and must be validated in order to demonstrate that it is a realistic representation of the real world (to be discussed in Section 3.2.6).

These problems aside, simulation as method has now gained traction in the fields of crime science and environmental criminology in particular. Examples of how simulations have been developed and used to good effect in this discipline include Brantingham and Brantingham's (2004) model of routine activity theory showing how people interact with their environment, Groff's (2007) model of street robbery also based on routine activity theory, Birks et al.'s (2012) burglary model which is used to test the sufficiency of routine activity theory, rational choice theory and crime pattern theory in generating credible burglary patterns, and Hill et al.'s (2014) poaching simulation, in which the interactions of animals, poachers and rangers are replicated and their movement analysed.

3.2.3 Types of Simulation Model

Simulation modelling techniques can broadly be divided into equation-based and agent-based models (Parunak et al., 1998). The key difference between these two methods is in whether it is the observables or the individuals in the system that are being modelled. Equation-based models (EBMs) work by constructing equations that describe the relationships between the observables: for example the relationship between the time somebody arrives in a queue and the length of time they stay in it. Agent-based models (ABMs) work the opposite way, instead starting with the behaviours of individual "agents", defining the rules by which they interact with each other, and then simulating these interactions to enable assessments to be made about the observables. ABMs have some advantages over EBMs, as they can be easier to construct and understand, they allow for the exploration of "what if" scenarios through changing the interactions and behaviours at the individual levels, and they have an extra level of validation available as the model can be tested at either the system or individual level (Penny et al., 2013). ABMs are extremely flexible as they allow for heterogeneity across the individual agents in the model, which is especially important in social science where individuals can be allocated different attributes, such as socio-demographic characteristics, personality traits, or even different levels of information with which to make decisions (Epstein, 1999). However where the rules by which individual agents behave are too complex or where there is insufficient data for these rules to be determined, equation-based models can be more appropriate.

Within these broad categories are a range of specific techniques that have been developed to suit particular applications. Agent-based models can be spatial or organisational, or a combination of both. Spatial ABMs provide a representation of a geographical area, most usually using cellular automata — an array of cells, where each cell has a state associated with it — to represent the spatial part of the model (Gilbert and Terna, 2000). Organisational ABMs are more abstract and can be thought of as a graph; these are a popular way to describe social networks, with nodes representing individual people or organisations, and links representing some form of affiliation or other relationship between the entities, all of which may change over time. ABMs are first and foremost theoretical models, although researchers have noted that the role of empirical research in model calibration and validation has been increasing (Hedström and Manzo, 2015), making today's ABMs more relevant and realistic than previously.

Numerous non-agent based approaches have also been developed: types of equation-based model include models based on queuing theory, and system dynamics models which represent social systems and processes in terms of levels and rates (Cioffi-Revilla, 2014). Alternative categories of models also exist, such as state-transition models (STMs). These models describe how entities in a system transition from one state to another, sometimes with probabilities attached to each transition (Siebert et al., 2012). They can operate either at the individual level, where each individual follows their own state-transition process, or at the cohort level, in which case the model is an example of a Markov model. The output from an individual-level STM would be how many people are in each state, while the output from a cohort-level STM is the probability that the cohort is in each state. STMs have the advantage over other types of simulation model that they are able to reflect the passing of time, and in particular that time-dependent parameters can be included in the model. An STM can generally also be written as either an EBM or an ABM (depending on whether it is a cohort or individual-level STM); it is therefore simply a different way of representing a model.

Non-computational simulation methods also exist, although these are generally more limited in scope: an intriguing example is the biological approach taken by Adamatzky et al. (2012) using an organism called "slime mould" to simulate efficient networks, such as the motorway network in the Netherlands. While such a method presents an interesting alternative and shows that computational models are not the only solution to research problems, such an approach would be unable to provide a generative explanation for a social phenomenon — and this is one of the key benefits of using simulation models for crime science research.

It can be concluded therefore that there exist a large number of mathematical tools that could potentially be of use when building a simulation model of a social system. Additionally, a model can be deterministic, where an effect always follows a cause, or stochastic, where an element of randomness exists (Keeling and Rohani, 2008, p. 190). How then to determine what is the most appropriate modelling method for a particular problem? The answer to this question depends on the system being modelled, but it also depends on the reason for constructing the model in the first place.

There are a number of reasons why one might want to construct a simulation model, such as:

- to better understand a system;
- to predict a future state of a system;
- to act as a substitute for a human — for instance to allow non-experts to make use of expert knowledge;
- for training — for example flight simulation;
- for entertainment — some simulations also act as computer games; and
- to assist scientists to formalise a system (Gilbert and Troitzsch, 1999, p. 5-6).

A model designed for one purpose may not be suitable for another, and it is likely that the modelling techniques used will vary accordingly. However these different purposes are not necessarily completely incompatible with each other — for instance, a model that successfully predicts the future state of a system should also facilitate the understanding of that system, and may also assist with formalisation. Predictive models need to be sufficiently accurate in their imitation of the real-world system they are representing to produce realistic results. Models designed for understanding have lower requirements in terms of their accuracy and complexity, but clearly must be accurate enough to include the most important causal relationships within the real-world system. So what level of accuracy is sufficient? An entirely accurate model is impossible to achieve by definition, as every model simplifies reality to some extent, but care must be taken that the right simplifications are made and that variables affecting the system's outcomes are not accidentally ignored.

The decision over to what extent to simplify a system when constructing a model can be described in terms of levels of abstraction. For high levels of abstraction more details are left out of the model and a larger conceptual leap must be made when interpreting the conclusions from the model in a real world context (Gilbert and Troitzsch, 1999, p. 19). At the extreme of this, the model may be so simple that it fails to contribute anything new to the field of knowledge, or it may even be so unrealistic that incorrect conclusions are drawn from it. At the other end of the spectrum, a model with very low levels of abstraction will include far more details of the real world system, but it may be too complex to be useful — as the developers of the early simulation models from the 1960s discovered. As a model's complexity increases the requirement for the accurate estimation of the model's parameters and the relationships between different system components also increases. If these parameters and relationships cannot be estimated from our knowledge of the real world, the model will be impossible to parameterise correctly and its conclusions will be misleading.

In order to strike the right balance one must refer back to the main purpose of the model, consider what assumptions will need to be made for the model's construction, and determine what data needs to be collected for its parameterisation (Keeling and Rohani, 2008). If, in order to serve its purpose, the model needs to be more accurately parameterised than is possible to do given the available data, then the justification for modelling the system must be called into question. It is therefore essential before proceeding to examine what the requirements for data are in the current case.

3.2.4 Data Requirements for Models of Social Systems

As the previous section made clear, to create a model one first needs data on the real world system that the model aims to replicate. This data is used at a number of different stages in the model building process.

The first application for data in model-building is to generate a hypothesis as to what the relationship(s) between the component parts of the system might be. In the simple ice cream selling example the modeller would have needed a certain amount of real-world knowledge in order to guess that there might be a relationship between the weather and sales of ice creams in the first place. This is what Hume would have termed "experience", and it is this that allows the possible causal relationships in the system to be hypothesised.

With further data the modeller can proceed to the second application: quantifying the relationships between the independent and dependent variables. In the ice cream selling example this is the stage where data on the number of ice cream sales and the temperature each day is collected and a statistical analysis conducted in order to establish what equation best describes the relationship between them. Exactly the same is true for a simulation model of a complex system, the only difference being that more complex systems require more statistical analyses to be conducted on a greater number of variables.

Once the modeller has reached this stage they would then be able to put together the simulation model, run it, and observe the results. A third application for data would then be to test or validate the model by comparing the results generated by the simulation with the real world (Cioffi-Revilla, 2014). In the ice cream selling example, the researcher would do this by predicting the number of ice cream sales figures for each different daily temperature using their model, and then establish whether the calculated sales figures are a good approximation to the real sales figures using a suitable statistical test such as a χ^2 test.

The ideal situation for the model builder is to have unlimited, perfect data to use at each stage. However, when the modeller is seeking to model something as complex as a human social system, the data available will be limited and far from perfect. Indeed the social systems that this thesis is seeking to model — criminality development and radicalisation — are ones where social scientists have long acknowledged difficulty when it comes to collecting good data (Tilley, 2002; Lum et al., 2006; Knutsson and Tilley, 2009). Part of the problem lies in the difficulty of observing when somebody actually does have the propensity to commit an act of crime or terrorism; as the direct causes of crime and terrorism include situational factors, there will be cases when somebody with the propensity for crime does not actually commit a crime, and conversely when someone who does commit crime actually has a relatively low propensity for it. These complicating factors are part of what makes the research question a difficult question to answer using conventional social scientific methods in the first place.

Does this mean that the criminality development and radicalisation processes cannot be modelled? This is essentially a question of whether a model can be developed that has sufficient "construct validity". Construct validity is one of a number of different threats that all scientific experiments face, and it relates to whether the way the model has been constructed accurately describes the system it is intended to represent (Townsley and Johnson, 2008). As already stated, there will inevitably have to be some simplifications made when a system is modelled, so the construct validity of any model will never be total. But if the construct validity is too low, the model will not be fit for purpose and will not be able to answer the research question. It is therefore essential to refer back to what we want to use the model for, and then to use this to decide what simplifications can be made.

In this case the main purpose of the model is to gain a better understanding of the criminality development and radicalisation processes. In terms of data requirements for the models, this means that there is certainly a requirement for data at the initial stage (Hume's "experience", which is needed to generate hypotheses). This we have already done, by using the IVEE framework to generate the research questions listed in Section 3.1. Additionally, there needs to be enough data to quantify the key relationships between the components of the criminality development and radicalisation processes, particularly where these relationships differ across the two processes. The literature examined in Chapter 2 includes a number of studies carried out by social scientists who have sought to do this for many of the different components of the processes. Consolidating the results of these should therefore provide the necessary data for the parameterisation of the models.

Finally, there needs to be sufficient data for the models to be validated. For a predictive model this would usually take the form of statistical significance testing of the model's outputs against real-world data which, as we have already discussed, is rather lacking in this field. However the main purpose of the models in this thesis is understanding rather than prediction, so a less rigourous validation method should be sufficient. A minimum requirement for data for model validation is the existence of a set of "stylised facts" against which the model outputs can be compared. The concept of stylised facts was introduced by Kaldor (1961) as a way to identify key observations that demanded explanation, with a stylised fact being a stable pattern that emerges from multiple empirical data sources (Heine et al., 2005). An example of a stylised fact in the field of crime science would be, for example, that relatively few offenders are responsible for the majority of crimes (Groff, 2007). Methods for validating models using stylised facts is described in Section 3.2.6.

In conclusion it is assessed that there should be sufficient data available for the models to be constructed in such a way that they will be able to answer to research question.

3.2.5 Which Modelling Technique To Use?

Now we have established that the criminality development and radicalisation processes can be modelled, and that doing so would answer the research question, it remains to decide which modelling technique would be the most appropriate. In order to determine this we need to consider the nature of the system we are modelling and the purpose of the model. The criminality development and radicalisation processes are processes that take place both in certain places and at certain times, and so an STM would be suitable. However STMs can be either individual-level (i.e. ABMs) or cohort-level. In this case the basis of the model will be the IVEE framwork, which operates on three levels — individual, ecological and systemic. As the framework includes detail of interactions and causal mechanisms at the individual level, an ABM would therefore be the most appropriate modelling technique.

Next we need to consider the purpose of the model, in order to determine the data requirements and whether the model should be deterministic or stochastic. In a deterministic model the entities change states with certainty, while a stochastic model incorporates randomness in the system by attaching a probability to each transition (Gilbert and Troitzsch, 1999; Keeling and Rohani, 2008; Cioffi-Revilla, 2014). Stochastic models are particularly useful where a model of a complex system is needed for prediction, as they account for uncertainty and the fact that not every causal factor in the real world system may be included in the model. However where a model is developed for the purpose of gaining a better understanding of a real world system a deterministic model is preferable, as they enable the direct impact of changing causal factors in the system to be assessed. The primary purpose of the model in this thesis is one of understanding, as the model must enable an improved understanding of two complex social processes in order to allow them to be compared. A secondary purpose, if it can be shown to be achievable, would be for the model to have some predictive capabilities that might prove to be useful to practitioners in the fields of crime prevention and counter-radicalisation, as this is ultimately the cause that, through answering the research question, this thesis hopes to assist. However as the primary purpose is one of understanding, for this project the models to be developed will be deterministic.

3.2.6 Model Validation

The challenge of how to validate a model describing a complex social process such as the development of propensity for crimes and terrorism was mentioned briefly in Section 3.2.4. However this problem is unique neither to this area of social science nor to simulation models, and a considerable literature concerning methods for validation in fields with little or no quantitative data exists. In particular this problem has been explored by social scientists using qualitative methods such as ethnography and phenomenology, and this is a good place to begin considering potential validation techniques for the models in this thesis. Elliott (1999) sought to consolidate the work that had been done in this area for qualitative research, and put forward a set of "evolving guidelines" for reviewing such research. The guidelines included ensuring adequate credibility checks, with suggestions for how this could be done comprising:

(a) "checking these understandings with the original informants or others similar to them;

(b) using multiple qualitative analysts, an additional analytical 'auditor', or the original analyst for a 'verification step' of reviewing the data for discrepancies, overstatements, or errors;

(c) comparing two or more varied qualitative perspectives; or

(d) where appropriate, 'triangulation' with external factors (e.g. outcome or recovery) or quantitative data." (Elliott, 1999, p. 222)

The end goal, says Elliott, is not to replicate the methods for validation that exist for quantitative data, but simply to show that the research provides meaningful and useful answers about the phenomenon under study.

A similar approach can be adopted when seeking to validate simulation models. Instead of attempting to validate the model's outputs against quantitative data that does not exist, a better approach is to consider the purpose of the validation exercise and use a technique suited to that purpose. In the case of validating a simulation model developed to further the understanding of a social process such as criminality development, the purpose of validation is to test whether the model replicates the desired phenomenon. In order to do this, we need to establish the features of the phenomenon — or, as Kaldor (1961) would call them, the stylised facts — and compare the model outputs with these. Ormerod and Rosewell (2009) explored how this might be done in the validation of ABMs of macro-economic processes, and noted that "the key aspect to validation is that the outcomes of the model explain the phenomenon. If the model explains the phenomenon under consideration better than previous models do, it becomes the current best explanation. This is the best we can expect to do." (p. 135)

The question then is how to undertake a model validation using stylised facts in practice. With the growth in popularity of modelling as a social science methodology in recent years more examples of model validation using stylised facts are emerging, but the technique is still in its infancy and no standard approach exists. The field of economics holds the most examples from which to draw. Ormerod and Rosewell (2009) is such an example, though their paper is more concerned with the legitimacy of using stylised facts for validation than the development of the method itself. Heine et al. (2005) however does demonstrate how it can be done in practice, by using the method to compare four models of collusion in a business environment. Heine et al. derive a list of six stylised facts; the authors state that ideally these would have emerged from a wider community of experts, but for their field these do not exist and they instead have to derive their stylised facts from the literature. They then proceed to assess how many of the stylised facts are addressed or partially addressed by each of the models they test, and they use this to determine which of the models best explains the desired phenomenon overall.

In the field of crime science there have also been some examples of the use of stylised facts. Hill et al. (2014) used stylised facts to test the realism of an ABM describing the behaviour of poachers in a Ugandan national park: for example, the authors noted that it is known that poachers typically place snares very close to water points. When the ABM failed to replicate this phenomenon, this suggested that the mechanisms in the process were not being faithfully replicated and the model needed modification. This demonstrates that using stylised facts for validation is a technique strong enough to fulfil the Popperian requirement that a theory (or in this case, model) can be falsified.

However in order for the models in this thesis to be able to be validated using stylised facts, a suitable list of stylised facts about the phenomena being modelled needs to exist. First let us take the phenomenon of the development of criminal propensity. By drawing on the literature discussed in Chapter 2, the following list describing features of criminal propensity that the model should seek to replicate can be put forward:

1. The agents in the model should be heterogeneous with regard to criminal propensity (i.e. the people in the model should not all have the same propensity for crime);
2. The distribution of propensities across the population should be positively skewed (i.e. a small proportion of people should have a high propensity for crime);
3. An individual's propensity for crime can increase or decrease over time;
4. A steady state for the system overall should not be reached (i.e. individual propensities can continue to change throughout);
5. Average propensity for crime reduces with age.

A similar list can be constructed for stylised facts associated with radicalisation:

1. The agents in the model should be heterogeneous with regard to radicalism (i.e. the people in the model should not all have the same propensity for terrorism);
2. The distribution of propensities for terrorism across the population should be much more positively skewed than the distribution of propensities for crime (i.e. a very small proportion of people should have any propensity for terrorism);
3. An individual's propensity for terrorism can increase or decrease over time;
4. A steady state for the system overall should not be reached (i.e. individual propensities can continue to change throughout);
5. Radicalising moral contexts (i.e. settings) should be far rarer than criminogenic moral contexts.

There is considerable overlap between these two lists, as should be expected following the literature review into how people develop the propensity to commit acts of crime or terrorism. The key differences between the two lists are that radicalisation

— both in terms of the propensity of the people and the settings — is far less common than criminality, and that the stylised fact concerning the negative correlation between propensity and age need not apply to radicalisation. This last difference is because there is not enough data about radicalised individuals to demonstrate that there *is* a correlation with age; such a correlation may exist, but due to the rarity of radicalisation in society this cannot be proven or disproven at the current time.

These lists of stylised facts will be compared with the models' outputs, and if the models are found to successfully produce these effects they will be considered sufficiently validated for the purposes of answering the research question.

3.3 Research Design

3.3.1 Overview

The research design for this project can be broken down into a series of stages as follows:

1. Establish the theoretical framework that will form the basis of the simulation models (i.e. the IVEE framework)
2. Use secondary sources to determine the precise relationships between different component parts in the IVEE process for the criminality development model.
3. Define the criminality development model.
4. Decide on a computer programming language to use and then code the criminality development model.
5. Run the simulations, changing the parameters in order to establish the sensitivity of the model.
6. Validate the model against the list of stylised facts in Section 3.2.6
7. Determine from any available secondary data sources in what way the crim-

inality development model would need to be altered to make it applicable to radicalisation.

8. Define the radicalisation model and code it.
9. Run the simulations for the radicalisation model and validate the outputs against the list of stylised facts in Section 3.2.6.
10. Compare the model descriptions and outputs for the criminality development and radicalisation processes and use these to answer the research question.
11. As further work, incorporate interventions specifically designed to target each process, and test their effectiveness against the other process. This will provide additional clarity as to the extent to which the processes are alike.

3.3.2 Validity of the Research Design

There are a number of threats to the validity of all science experiments that should be considered for every proposed methodology, and this project is no exception. If inadequately mitigated these threats call into the question the validity of the experiment and thus the accuracy of the conclusions that can be drawn from it (Campbell, 1957). Construct validity was discussed and addressed in Section 3.2.4, but there are several other threats to validity to consider.

3.3.2.1 Internal Validity

Internal validity is primarily concerned with causality: that is, whether a change in independent variable x really causes a change in dependent variable y (Bryman, 2012, p. 47). The threat to internal validity of greatest concern in this project is over whether the causal chains in the model describing the criminality development and radicalisation processes can be supported. The model describes a complex social system and assumes that, for instance, exposure to a radicalising narrative in someone cognitively susceptible causes them to experience an increase in radicalisation. How can it be determined whether this causal link is true?

The mathematical model that will be constructed is based on the IVEE framework for criminality development that was introduced in Chapter 2. The IVEE framework was in itself developed with the specific aim of understanding the causes and causal processes in criminality development, and was built from the bottom up with sound empirical backing. It is therefore safe to conclude that if the final mathematical model is a fair representation of the IVEE framework that it will be strong on internal validity from the perspective of causality.

There is another side to internal validity that is particularly important for projects involving simulation, and that is verification (Townsley and Johnson, 2008, p. 6). Verification involves ensuring that a computer model does not contain programming bugs and that it formalises theory correctly. There are a number of ways to address this issue, such as having a second party check over the computer program, and inputting some extreme or trivial examples into the simulation to check that the results come out as expected. These should be done as a matter of course.

A final aspect of internal validity of particular relevance to modelling is avoiding "the logical fallacy of the circular argument, where an assumption is used to prove itself" (Townsley and Johnson, 2008, p. 7). This would be a concern in this project if the data used to develop and parameterise the model were also used to validate the model. However in this project the models being developed are only intended to provide a better understanding of the criminality development and radicalisation processes rather than act as predictive tools, and so they will not be validated against real-world data. The logical fallacy of the circular argument will therefore be avoided. This does however have implications for empirical validity (discussed later).

3.3.2.2 External Validity

External validity is concerned with generalisability (Bryman, 2012, p. 47-48). How applicable are the findings of the research to other settings? In this project this question must be answered at two levels, as external validity is equally necessary for both the underlying IVEE framework and the computer simulation itself.

IVEE is an analytical framework that enables observations on the complex social processes of criminality development and radicalisation to be synthesised and explanations found. The importance of the geographical environment as a causal factor in these processes is a key part of IVEE, implying that the framework is applicable in a variety of settings. As has already been noted, it was developed from the bottom up and is based on a number of empirical studies which themselves have taken place in different settings, suggesting that IVEE is high on external validity. However as the framework is still relatively new (having only been developed in 2011) the full extent of its applicability is yet to be determined.

The computer simulation itself is far easier to assess in terms of external validity. As it will have both a geographical input and a population input, it can be made applicable to other settings and situations simply by changing these inputs.

3.3.2.3 Ecological Validity

Ecological validity asks whether the findings in a research project are applicable to natural social settings (Bryman, 2012, p. 48). This threat to validity is more a concern in physical science experiments where certain results occur under laboratory conditions that cannot be replicated in the world outside. The sociological studies that have contributed to the development of IVEE such as Wikström (2011b) and Sampson (2009) have taken place in natural settings and are therefore themselves high on ecological validity, so it only remains to ask whether the computer simulation is applicable to natural settings — and that is more a question of empirical validity.

3.3.2.4 Empirical Validity

Empirical validity is a concern exclusive to research that uses modelling as part of the research design. It relates to the fact that a model will only be considered credible if it can be shown to replicate reality (at least to a certain extent) (Townsley and Johnson, 2008, p. 10). The notion of empirical validity thus has some overlap with construct validity, in that it highlights the need to use empirical data for model parameterisation. However empirical validity goes further, as there also has to be some means of testing whether the model outputs are realistic. Methods for how this could be done were discussed in Section 3.2.6, and this potential threat to the validity of the models will be addressed by validating the model outputs against the stylised facts listed in that section.

As has already been noted, a model will never precisely replicate reality as some simplifications will always be made. It is therefore also essential for the assumptions made during the construction of the model to be made clear, so that the results can be put into context.

3.4 Ethical Considerations

All research projects with an interest in the social world faces ethical issues. However as the research design does not require any data collection from human participants the usual ethical concerns associated with social research (such as the protection of participants' data and ensuring their privacy or anonymity) are not an issue in this project. Instead the key ethical issues to be faced involve the potential uses of the outcomes of the research, and especially if it could be open to misinterpretation. There is also the possibility of dual use arising from the outcomes of the project, for instance if the research is used by policy-makers in government to support a controversial policy that might have other negative consequences for society, such as a policy restricting the personal liberty of the public.

Misinterpretation of the results of the project might occur if the simulations were thought to resemble reality more closely than they do. This could result in the simulations' outputs being mistaken for predictions and, as a worst case scenario, used as the basis for policy decisions in the fields of crime prevention and counter-radicalisation that are actually counter-productive. This would damage the credibility of the research, and could also potentially have a detrimental social impact. In order to prevent this it is essential that the limitations of the models are made clear and the results kept in context.

The second ethical issue over the potential for dual use of the research is connected to the first, as it also involves the research being used to influence policy in a way that is not intended by the researcher. The actions already suggested — that of ensuring that the limitations of the models are known and the results interpreted within the intended context — provide some mitigation against this. Additionally, the researcher can take positive action to prevent this by promoting the research directly among interested stakeholders, be they academic researchers or those involved with public policy, and in so doing ensure the context of the research is fully understood.

Chapter 4

Modelling the Criminal Propensity Development Process

Chapter 2 examined how the process of radicalisation can be thought of as a special case of the process by which an individual's propensity for crime more generally develops, and proposed the IVEE theoretical framework for radicalisation as a suitable basis upon which a computer simulation describing the process of criminal propensity development can be built. This chapter describes the development of such a computer simulation. A full description of the final model developed over the course of this chapter is at Appendix A.

The first section of this chapter analyses the available data that may enable the causal factors in the IVEE process and the relationships between them to be measured. The second section provides an overview of the resulting mathematical model representing the whole process. The chapter concludes with a short appraisal of the changes that would need to be made to the model to make it applicable to the specific case of radicalisation.

4.1 Building The Computer Simulation

Chapter 2 examined the theory behind IVEE and established what the different levels in the model are and how they interact. But in order to turn this theoretical model into a computer simulation it is necessary to determine the precise relationships between the causal factors and find ways to measure them. In particular:

- How can someone's propensity for criminal behaviours be measured?
- How can exposure to criminogenic moral contexts be measured?
- How can someone's cognitive susceptibility be measured?
- How do cognitive susceptibility and exposure to criminogenic settings interact and relate to propensity for criminal behaviours?
- What environmental factors make a setting more or less likely to become criminogenic?
- How are these environmental factors to be measured?

The following sections seek to answer the above questions using data where it exists, and this will then be used to construct the computer model. However it must be re-iterated that all models are simplifications of reality, and that reality can never be completely replicated by a computer simulation. Additionally, the field of crime research is particularly challenging with regards to the collection and analysis of data due to the complexity of the social and environmental factors involved, and the fact that the only way to know whether someone has a propensity for crime is after they have been convicted of a criminal offence — and even then, the situational factors at the time of the event may be just as significant as the offender's criminality.

The following sections will therefore make a number of assumptions and generalisations in order to enable the construction the computer simulation. These will be stated explicitly and will be discussed in greater detail in Chapter 8 when examining the limitations of the research more generally.

4.1.1 Measuring Propensity for Criminal Behaviours

In order to study crime and to better understand the effectiveness of interventions, criminologists have proposed a number of different metrics. Some metrics have been developed with the aim of comparing crime rates across different locations; others have been developed for research investigating offenders' desistance from crime. All require some form of measurable outcome, which may consist of instances of crime from official police data, self-reports of offences committed, or self-reports of victimisation. All have different advantages and disadvantages, and serve different purposes for researchers.

Crime metrics invariably involve some form of count data, but the specifics of what is being counted varies. Some studies simply count whether an offence has been committed, others look at the frequency of offences, while still others create aggregate measures. However no method is without flaws. Metrics that simply count whether a person has committed a particular type of offence hide potentially significant differences in offender behaviour: a person who has committed common assault once is judged the same as someone who commits it every month. But including the frequency of the crime still ignores situational factors that may cause someone to commit a crime more often. It can also be argued that if it is the person's *propensity* to commit a crime that is of interest, then the frequency of the offence is not important — if an offender has committed an offence a couple of times they must have sufficient propensity to do it in certain situations, but the fact that they may have committed the offence more often than this would not provide any more insight unless far more is known about the situational factors surrounding each of the crimes.

Also to take into consideration when using count data is the reliability of the underlying data that is being counted. Are the crimes self-reported or are they official data based on convictions? Again, both have flaws. Official records of convictions will always underestimate the number of offences, as not all incidents will have been identified and processed by the criminal justice system (MacDonald et al., 2014). However self-reported data depends on individuals being open and honest about their involvement in illegal activity, and on them accurately remembering past events (Piquero et al., 2002).

Victimisation data adds another dimension again. For offences against static targets such as property, victimisation data tells you about the locations that encourage someone with a certain criminal propensity to commit a crime. However victimisation data against people is less useful unless combined with data about the victim's pattern of life, which might then enable the researcher to build up a picture of the situational factors surrounding the crime. For research seeking to understand how the propensity of offenders develops, however, victimisation data is less useful than official crime statistics or self-reports of offences.

Despite their limitations, counts of criminal incidents do provide an important measure of what proportion of a population might have the propensity for certain criminal behaviours. Additionally, this data can be enhanced by considering what other offences an individual might have the propensity for, if they have already demonstrated through their actions that they have a propensity for one offence in particular. There are two ways in which such inferences could be deduced: firstly by considering the relative severities of the crimes, and secondly by considering the similarity of different crimes

A number of metrics exist for measuring the severity of a crime, such as how tough the sentence is for the crime in question, the extent of the harm done to the victims, or the economic impact on society (MacDonald et al., 2014). While there are differences in the scores these ranking systems give to different crimes, there is enough similarity between them to objectively conclude, for instance, that homicide is a "worse" crime than vandalism. By taking a small step of logic it can be deduced, at least from a moral perspective, that someone who has committed arson would also have the propensity to commit more minor forms of vandalism, such as graffiti. Much care must be taken in drawing such conclusions however; for instance, while the general public in the UK would probably agree that homicide is a worse crime than drug-taking, some convicted murderers may object to drug-taking on ethical grounds and would not have the propensity to do it.

A second way to use count data to infer the prevalence of criminal propensities in the population is to use *crime similarity*, which is a concept put forward by MacDonald et al. (2014) in their study on whether crime specialisation in criminal careers is related to the severity of their offences. The authors' definition of crime similarity is entirely empirical, in that it is simply the likelihood that two offences are committed by the same person. This avoids the difficulty of trying to decide, for instance, whether all property crimes are more alike than all violent crimes. Massoglia (2006) conducted a similar study, in which he developed a typology of offenders determined by the activities they were more likely to engage in. For example his "predatory" offenders were more likely to be involved in theft, vandalism, and general violence, while his "drug" offenders were much less likely to be involved in any of these actions, but would likely take both marijuana and hard drugs.

Such measures as crime similarity and scales of offence severity enable deductions to be made as to whether a person convicted of offence *A* might also have a propensity for offence *B*, and hence go some way to tackling the problem of underestimation that is inherent in data consisting of counts of criminal incidents. However, there is an alternative way to measure an individual's propensity for crime, which goes back to the way crime propensity was originally defined in Section 2.1.2.2.

That definition of criminal propensity was taken from Wikström's Situational Action Theory. According to this definition, criminal propensity has two components: morality and self-control. It therefore follows that a metric measuring an individual's criminal propensity can be constructed by creating a composite measure based on scales measuring an individual's morality and their capability to exercise self-control. And indeed, this is precisely how Wikström measures criminal propensity in his research on the effects of the environment on the criminal behaviour of adolescents in the UK city of Peterborough (Wikström, 2009a). He measures both morality and self-control by means of a questionnaire, where respondents are asked to answer questions about how wrong they consider certain behaviours to be (to measure morality) and how able they are to control their actions (to measure self-control). Each score is then converted into a z-score, and the criminal propensity measure is the sum of these two z-scores.

This measure has been shown to be significantly correlated with crimes actually committed (calculated using a self-report questionnaire). Further, statistical models featuring this measure of crime propensity along with a measure of exposure to criminogenic settings show that both variables are statistically significant predictors for crime involvement (Wikström, 2009a, p. 260). This finding not only supports Wikström's Situational Action Theory, it also suggests that his way of measuring crime propensity has considerable construct validity. However, it is worth noting that the dependent variable (self-reported crimes actually committed) only includes a small number of types of crimes — for instance, crimes of fraud, sexual crimes and traffic crimes are excluded. Additionally no distinction is made between the different types of crime that an individual has the propensity for in the measure, which prevents the ability to examine whether Wikström's crime propensity measure correlates better with some crimes than others.

It can be concluded that there are a number of ways to measure an individual's propensity to commit crime, each of which have advantages and disadvantages. However it is important to recognise the differences between the methods used by different researchers, as these differences may impact on how the causal factors that each researcher is testing correlate with their chosen measure of criminal propensity.

4.1.2 Measuring Exposure to Criminogenic Moral Contexts

In order for a person to be exposed to a criminogenic moral context there are two requirements: firstly, a setting needs to have developed a criminogenic moral context, and secondly, a person needs to go there. There are therefore two sides to measuring the amount of exposure that a person has to criminogenic moral contexts: the first is the extent of the criminogenity at the setting, and the second is the amount of time the person spends in such an environment.

For simplicity, during the initial development of the model only physical locations will be considered; extending the model to incorporate non-physical locations will be explored in Chapter 6.

4.1.2.1 Extent of criminogenity

As was the case with measuring criminal behaviours, when seeking to find a way to measure the extent of criminogenity to which an individual becomes exposed it is possible to draw on previous research conducted by criminologists in this area. In particular, a number of studies have investigated the relationship between peer delinquency and an individual's own delinquent behaviour (Brendgen et al., 2000; Elliot and Menard, 1996; Farrington, 2004; Heinze et al., 2004; Lipsey and Derzon, 1998; Patterson et al., 1991), with more recent work seeking to distinguish between cause and effect — that is, whether a delinquent person chooses delinquent peers, or whether they are influenced by those peers (Monahan et al., 2009; Miller, 2010; Meldrum et al., 2013).

These studies use a variety of ways to measure the extent of delinquent behaviour among respondents' peers. Many are based on the "Peer Delinquent Behavior Scale", which is an eight-item scale developed by Thornberry et al. (1994). Respondents are asked how many of their friends had committed delinquent acts in the past six months, with delinquent acts ranging in severity from skipping class to armed robbery. The responses are then coded from 4 (for "Most of them") to 1 (for "None of them"). This measure therefore relies on an individual's *perception* of the delinquency of their peers rather than the peers' actual delinquency. This could arguably be either a strength or a limitation: if it is supposed that the criminogenic influence of peers is based only on an individual's perception of their behaviour then it would be a strength, but if a peer still exerts criminogenic influence regardless of the individual's knowledge of their actions then it would be a weakness. A second weakness is the requirement for the individual's peers to have already committed a delinquent act; a peer with the propensity for delinquency but who has not yet committed a delinquent act (perhaps due to situational factors) might still have an antisocial influence on the individual, but this would not be captured in the delinquency scale.

An alternative to asking individuals about the behaviour of their peers would be to use data about the actual behaviour of their peers, which could either be based on official crime figures or on self-reports of behaviour. This has the advantage that it does not require the individual to know all the details of their peers' behaviour which, as previously discussed, may be viewed either as a strength or a weakness of the measure.

Recall, however, that the IVEE framework focuses on the *settings* that attract people with the susceptibility to commit crime, and the selection mechanisms that lead an individual to go to these same settings. This adds an element of complexity, as the studies using peer delinquency measures only consider the influence of social networks, not of settings. However, as discussed in Chapter 2, crime happens as a result of a person-environment interaction. People are always in settings of some form or other, and so if a person is influenced by their peers this influence will happen when they are in some setting. Indeed, the level of influence a peer has on an individual is unlikely to be uniform across all places and all times; in particular, if the influence is criminogenic in nature it is more likely to take place in unsupervised locations (Wikström, 2009a). IVEE's focus on settings rather than social networks therefore provides additional flexibility, as it allows for people to be influenced by more than just their social network (for instance by something they read online), and it enables the influence of their social network to vary according to the setting.

It is necessary therefore to determine a measure for the criminogenity of a setting that incorporates both the influence of peers and of other features in the environment. The influence of peers can be integrated into the computer simulation by generating activity fields for each individual (the method for which will follow in the next section). When a (simulated) individual regularly goes to the same setting as another (simulated) individual, the two individuals can be considered affiliates and their respective propensities for criminal behaviours can be made to contribute to each others' exposure to criminalising moral contexts.

The question of how to incorporate environmental features in measuring the extent of the criminogenity of settings relates to emergence and in particular how levels of collective efficacy can be measured. This will be examined in more detail in Section 4.1.5.

4.1.2.2 Time spent in criminogenic settings

Social selective factors can be incorporated into the model by making assumptions about the activity fields of individuals based on socio-demographic information, such as a person's age, religion and occupation. For instance, if the average British school pupil attends school between 8:30am and 3:30pm every Monday to Friday, we can assume that the average length of time they spend at school is approximately 35 hours per week. Similar estimates can be made for other socio-demographic groups, such as:

- Students over 18 spend approximately 40 hours per week at university;
- Employed people spend approximately 40 hours per week at their work-places;
- Religious people attend their place of worship for approximately 2 hours per week;
- Unemployed people and those with no religion spend their extra time at home, at friends' houses, or in public social centres (equally distributed);
- Only those aged under 20 go to youth clubs.

These estimates can be combined with individual factors such as lifestyle choices and personal preferences to create a model simulating each person's activity field. In Section 2.2.1.2 several assumptions were put forward as to why an individual would be more likely to go to one setting over another. In particular it was suggested that people are attracted to places closer to where they live, places that are large, and places where like-minded people go. How can these factors be combined in such a way as to enable an individual's activity field to be estimated?

The first two assumptions have been used in a number of previous studies that have sought to understand how many people go to certain locations, such as studies modelling the popularity of retail centres (Harris and Wilson, 1978), and research into the locations that attracted rioters in London in August 2011 (Davies et al., 2013). This previous work provides the basis for a model describing how likely it is that a person visits a certain setting.

The original model, developed for retail modelling by Harris and Wilson (1978), suggests that given a flow f_{ij} of money from location i to location j:

$$f_{ij} = A_i Q_i W_j^{\alpha} e^{-\beta c_{ij}}$$

where $A_i = \frac{1}{\sum_k W_k^{\alpha} e^{-\beta c_{ik}}}$ so that $\sum_j f_{ij} = Q_i$.

In this equation W_j is the "attractiveness" of the setting and relates to its size; c_{ij} is a measure of the cost of travel from i to j, for instance the distance between the two; Q_i is the retail demand in location i, which is a measure of how much the people in location i go out to buy things in general; and α and β are model parameters (Harris and Wilson, 1978, p. 371).

This equation can be used to estimate the likelihood that each individual person i visits each setting j. In other words, the f_{ij} function provides a means of estimating a person's activity field.

In order to calculate f_{ij} some further information is required: in particular about the location of each setting (to calculate the cost c_{ij} of going there for each person), and about the setting's size (to calculate the attractiveness W_j). However, the original retail model is very limited in the way it calculates the attractiveness W_j of setting j, as it implies all settings of the same size are equally attractive to people from all originating locations i (which is why W_j is dependent only on j, not on i). The criminal propensity development model requires more sophistication in how attractiveness is calculated, as it is important to incorporate the attractive influence of like-minded people at the setting (homophily). In order to do this it will be necessary to make W_j into W_{ij}, dependent on attributes of both i and j, and in particular this will be done through a function measuring how similar a person is to other people who visit that setting.

As this is a model rather than reality, there are only a limited number of variables ascribed to individuals that can be used to measure how similar a person is to others visiting a setting: for instance the person's age, religion, cognitive susceptibility, and propensity for crime. These can be coded so that, for instance, those in age bracket 14-18 have value "1", 19-24 have value "2" etc. In the simplest instance it will be assumed that all factors to have equal weighting when it comes to defining similarity. The similarity between a person and a setting will then be calculated as the difference between an individual's personal characteristics and the mean average of these characteristics for people who have visited the setting. The overall attractiveness W_j of setting j will then be a composite variable made up of both setting j's size and its similarity to person i. W_j in the retail model thus become W_{ij} in the criminal propensity development model.

The variable that requires the most careful handling to make it transferable to the criminality development model is Q_i, originally described in the retail model as the retail demand in location i. The equivalent for this model would be the proportion of time that person i spends at a particular type of location — for instance a place of work (such as a school, university, or office) or a place of leisure (such as a high street, youth club or sports centre). The list at the start of this section comprising estimates for how long people with certain demographic characteristics are likely to spend in particular locations is a good place to start; these estimates allow the value of Q_i to be determined for each (simulated) person in the model given their socio-demographic characteristics.

However, defining Q_i is not quite that simple. In the original retail model the variable Q_i represents the general spending power of people from location i, and is therefore dependent only on the originating location i, not on the receiving location

j. But the assumptions at the start of this section relate to the different types of setting that person i goes to, and hence it is necessary to make Q_i dependent on the type of location that j is.

We must therefore define the set K of setting types, comprising schools, universities, offices, leisure centres, youth clubs, high streets, mosques, churches, and personal residences (i.e. someone's friend's house).[1] K is such that family $\{J_k\}_{k\in K}$ is a partition of J, the set of all settings. In this way Q_i from the retail model becomes Q_{ik} in the criminality development model, for $k \in K$. The assumptions at the start of this section can then be used to determine the specific values of Q_{ik} so that, for instance, if person i is aged under 18 and location type k is a school, $Q_{ik} = \frac{35}{16\times 7} = 0.3125$ (assuming people are awake for an average of 16 hours per day).

To summarise, the self- and social-selection elements of the IVEE model can be represented as an activity field, which can be estimated using the function

$$f_{ijk} = A_{ik} Q_{ik} W_{ij}^{\alpha} e^{-\beta c_{ij}}$$

where Q_{ik} represents the amount of time person i spends in settings of type k, W_{ij} represents the attractiveness of setting j to person i, c_{ij} represents the cost to person i of going to setting j, α and β are model parameters, and $A_{ik} = \frac{1}{\sum_{l\in J_k} W_{il}^{\alpha} e^{-\beta c_{il}}}$ is a scaling factor that makes $\sum_{j\in J_k} f_{ijk} = Q_{ik}$.

4.1.3 Measuring Cognitive Susceptibility

Section 2.2.1 explored what makes a person cognitively susceptible to developing the propensity to commit acts of terrorism, and found that there are specific areas of the brain that are either more likely to be activated or are less well developed in such individuals. However, without conducting fMRI scans on the brains of a significant sample of the population, it is difficult to use this definition to measure cognitive susceptibility in the criminality development model. It is therefore preferable to

[1] Further elements could be added to K to refine this part of the model further, assuming that accurate information could be obtained regarding the amount of time people spend at the additional location types.

measure the cognitive susceptibility of a person by means of a self-report measure or a proxy.

As already discussed, Gottfredson and Hirschi and many other criminologists have linked lack of self-control to increased criminal activity. There are various methods that these researchers have used to measure self-control. Some consist of variations of the Stroop task which tests executive function capacity (Stroop, 1935). Another popular example is the Child Behavior Checklist (Achenbach, 1991), which has been used in several criminological studies (Chapple, 2005; Hay and Forrest, 2006; Meldrum et al., 2013). This comprises a questionnaire filled in by mothers or adolescents, asking the respondents to rate certain statements such as “throws temper tantrums or is hot-tempered” in terms of how often they are true. Grasmick et al. (1993) have also developed a scale which includes some questions on self-control that respondents are asked to rate, such as “I often act on the spur of the moment without stopping to think”. The most popular methods have been used sufficiently often to be known to have strong construct validity.

For measuring an individual’s vulnerability to moral change, there is one candidate which shows signs of being an appropriate proxy: a self-report measure called *Resistance to Peer Influence* (RPI). This measure was developed by Steinberg and Monahan (2007), and is calculated by presenting individuals with 10 pairs of statements and asking them to choose the statement that describes them best (for example, “Some people go along with their friends just to keep them happy” versus “Other people refuse to go along with what their friends want to do, even though they know it will make their friends unhappy”). This measure has been used in several large studies that have observed its statistical significance as a predictor of delinquent behaviour (Steinberg and Monahan, 2007; Monahan et al., 2009; Meldrum et al., 2013). It has also been shown to have a high level of construct validity (Steinberg and Monahan, 2007).

The relevance of RPI to criminal propensity is supported by prior research into susceptibility to peer pressure, with Erickson et al. (2000) noting that a heightened susceptibility to peer pressure has most consistently been seen when the behaviour is antisocial — that is, behaviours where morality would play a part in an individual's decision making — making RPI a measure that logically may be linked to a cognitive susceptibility to developing the propensity to commit crime. This link has since been demonstrated by a team of psychologists who used the RPI measure when analysing the results of fMRI scans conducted on a sample of 10 year old children exposed to a visual stimulus (Grosbras et al., 2007). Their findings showed that children with lower RPI scores experienced a higher response in three different brain regions. Two of these three regions are the dorsolateral prefrontal cortex and the anterior cingulate cortex — precisely those that have been associated with someone being more cognitive susceptible to changing their morality.

These findings suggest that RPI may be an appropriate proxy measure for an individual's cognitive susceptibility to moral change that can be used in the criminality development model. The question of how to measure cognitive susceptibility therefore becomes one of how to measure RPI. As a self-report measure based on people's responses to "either-or" questions, RPI lacks a meaningful unit; while studies using RPI (or similar measures) have shown that that there is a relationship between RPI and the likelihood of delinquency, this relationship is not linear. For instance if person A has twice the RPI of person B, this does not mean that person B is twice as likely to commit criminal acts (given the same exposure to delinquent peers and situational stimulus). A similar argument can be made for self-control, which is also often measured via a self-report questionnaire. In order for RPI and self-control to be used in the computer simulation the relationship between these variables and propensity for delinquency must be made quantifiable. Ways in which this has been attempted will be examined in the next section.

An additional point to address is how to allocate realistic cognitive susceptibility levels to the simulated people in the computer model, and whether it should be static or change with time. In order to do this the distribution of RPI in the general population needs to be determined, as does RPI's relationship with age. As measures of self-control vary from study to study a similar analysis cannot be carried out for this variable; it is however assumed to be normally distributed (Wikström, 2009a).

In a study conducted by Meldrum et al., the authors found that the distribution of susceptibility to peer influence is approximately normal in their sample of 908, with skewness=0.34 and kurtosis=2.75 (2013, p. 117). While their measure of RPI is slightly modified from the original measure developed by Steinberg and Monahan (2007), the differences are small and unlikely to have generated significantly different results from other RPI measures.[2] It is therefore reasonable to assume that the original measure of RPI as introduced by Steinberg and Monahan is also distributed normally across the population.

Steinberg and Monahan's original paper does provide information about the mean and variance of the RPI measure. The data analysed in this paper come from four studies that have taken cases from different parts of the USA and include both offenders and non-offenders, giving a total of 3,676 cases. The overall mean RPI across all cases is 3.07, with a standard deviation of 0.55 (Steinberg and Monahan, 2007, pp. 1534-5).

All analyses using the RPI measure agree that it varies with age over the period of middle adolescence (ages 14 to 18). However Steinberg and Monahan's analysis, which uses data with an overall age range of 10 to 30, notes little change outside this age bracket. Steinberg and Monahan applied several different models to their four datasets, with the model that best fitted the longitudinal dataset having RPI increasing linearly with age in the range 14 to 18, with the mean RPI of 2.78 at age 14 increasing by 0.09 every 6 months until age 18 (Steinberg and Monahan, 2007, p. 1538).

The models showed that this linear trend in middle adolescence is the same for both males and females, but that overall females have a higher RPI than males. This finding is supported by prior research showing girls generally to be less susceptible

[2] The changes consist of a simplification of the questionnaire to a traditional 4-point scale worded in the first person. See (Meldrum et al., 2013, p. 116) for details.

to peer pressure than boys (Berndt, 1979; Greenberger, 1982; Steinberg and Silverberg, 1986). Steinberg and Monahan's model suggests that males have a mean RPI of 2.68 at age 14 while females have a mean RPI of 2.88 at age 14, with RPI increasing by 0.137 every 6 months for both genders (2007, p. 1539).

It must be noted that this model applies only to the longitudinal dataset analysed by Steinberg and Monahan, which exclusively looks at serious offenders between the ages of 14 and 21. It is therefore possible that the mean RPI for these individuals is different from that of the general population. However, Steinberg and Monahan's analysis of the other three datasets (which mostly consist of non-offenders) shows no statistically significant difference between the mean RPIs of the serious offenders when compared with the wider population at each age.

It should also be noted that Steinberg and Monahan's analysis uses data exclusively from studies conducted in the USA. It is therefore possible that the difference in culture between the UK and USA would prevent a meaningful transferral of these results to the UK population. However, in addition to analysing the impact of gender and age on RPI, Steinberg and Monahan also examined the effects of several cultural factors, such as ethnicity and socio-economic status. They found only a very slight variation in RPI due to these cultural factors. RPI's linear relationship with age was also found to be consistent with Dutch and French-Canadian studies, suggesting that RPI is a measure largely independent of cultural factors.

For simplicity in the criminality development model, it is preferable to reverse the scale to create a measure for susceptibility rather than resistance to peer influence, and also to transform these values to z-scores so that the cognitive susceptibility variable follows a standard normal distribution. A value of 3.8 is taken for the overall mean in this transformation, which assumes that the population has a uniform distribution of ages between 14 and 60 and an even gender split. The differences in mean according to the individual's age and gender is shown in Table 4.1.

Table 4.1: Mean susceptibility to peer influence values

Gender	Age	Transformed Mean Susceptibility
Male	14	$\frac{3.8-2.68}{0.55} = 2.0364$
Male	15	$\frac{3.8-2.954}{0.55} = 1.5382$
Male	16	$\frac{3.8-3.228}{0.55} = 1.04$
Male	17	$\frac{3.8-3.502}{0.55} = 0.5418$
Male	18+	$\frac{3.8-3.776}{0.55} = 0.0436$
Female	14	$\frac{3.8-2.88}{0.55} = 1.6727$
Female	15	$\frac{3.8-3.154}{0.55} = 1.1745$
Female	16	$\frac{3.8-3.428}{0.55} = 0.6764$
Female	17	$\frac{3.8-3.702}{0.55} = 0.1782$
Female	18+	$\frac{3.8-3.976}{0.55} = -0.32$

4.1.4 Relating Cognitive Susceptibility, Exposure to Criminogenic Settings and Propensity

As highlighted in the previous sections, in order to simulate the effects that causal factors have on an individual's propensity for crime, each variable and the relationships between them have to be made measurable. This is difficult to achieve, as while self-control, RPI and peer delinquency have been shown to be strong predictors for delinquent behaviour, statistical models linking them ignore the situational factors that also contribute to an individual committing a crime. This limitation cannot be eliminated entirely, but the use of a large sample can provide some mitigation, as situational factors will be averaged out to a certain extent. This approximation is clearly imperfect, but as the studies that have used RPI as a measure have related it to actual instances of delinquency rather than by measuring propensity in the manner suggested by Wikström, it is an approximation that must be made in order to parameterise the computer model.

While several researchers have used RPI (or its converse, susceptibility to peer influence), the focus of most studies has been on linking it to factors such as gender and age (Steinberg and Monahan, 2007; Steinberg and Silverberg, 1986) or looking at interaction effects with other variables (Monahan et al., 2009; Miller, 2010). Only one study has explored the relationship between susceptibility to peer influence, self-control, peer delinquency, and the probability that someone will commit a crime, which is Meldrum et al. (2013).

For Meldrum et al.'s study the dependent variable was a composite self-report delinquency measure[3]. Meldrum et al. found that the most suitable statistical model linking susceptibility to peer influence, self-control, and peer delinquency to their delinquency measure was a negative binomial regression model. In this model, the number of different delinquent acts conducted by an individual of age 15 over a 12 month period is assumed to be a random variable Y such that the probability that a person commits y delinquent acts in the next 12 months is:

$$P(Y=y) = \frac{\Gamma(y+\frac{1}{\alpha})}{\Gamma(y+1)\Gamma(\frac{1}{\alpha})}\left(\frac{1}{1+\alpha\mu}\right)^{\frac{1}{\alpha}}\left(\frac{\alpha\mu}{1+\alpha\mu}\right)^{y}$$

The values μ and α can be calculated from the data. Meldrum et al. produced several models based on 908 data values, of which the most relevant is the one that assesses the impact on delinquency of susceptibility to peer influence, self-control, an interaction term (susceptibility $\times$ self-control), and peer delinquency. For each person in the sample Meldrum et al. calculated values for these attributes using self-report questionnaires (as discussed in the previous sections), then converted each of these values to z-scores in order to produce the final regression model. For this model the parameters were calculated as $\alpha = 0.1228$ and

$$\ln\mu = -0.23 + 0.25x_1 - 0.13x_2 + 0.15x_1x_2 + 0.69x_3$$

where x_1 is the z-score for the susceptibility to peer influence (SPI) metric, x_2 the

[3]The study uses 8 acts of delinquency in their measure; these act include threatening to beat someone up, purposefully damaging property, and using marijuana. For each of these acts there is a score of 0 if the individual has not done the act in the past 12 months, and a score of 1 if they have. The delinquency measure is therefore always between 0 and 8 (Meldrum et al., 2013).

z-score for self-control, and x_3 the z-score for peer delinquency. All p-values are less than 0.001.

Meldrum et al. do not refer specifically to criminal propensity; their model calculates the probability that someone will commit y acts of delinquency in a 12 month period, not their propensity to do so. Therefore in order to use this model to find a quantifiable relationship between susceptibility to peer influence, peer delinquency, and criminal propensity, propensity must be defined in terms of Y. As there is no information about the situational factors associated with each event, the most logical choice is $P(Y > 0)$, the probability that an individual commits any delinquent acts at all in a 12 month period. $P(Y > 0)$ must therefore be calculated to establish how it changes with the predictor variables:

$$\begin{aligned}
P(Y > 0) &= 1 - P(Y = 0) \\
&= 1 - \frac{\Gamma(0 + \frac{1}{\alpha})}{\Gamma(0+1)\Gamma(\frac{1}{\alpha})} \left(\frac{1}{1+\alpha\mu} \right)^{\frac{1}{\alpha}} \left(\frac{\alpha\mu}{1+\alpha\mu} \right)^{0} \\
&= 1 - \left(\frac{1}{1+\alpha\mu} \right)^{\frac{1}{\alpha}} \\
&= 1 - \left(\frac{1}{1 + 0.1228 e^{-0.23+0.25x_1-0.13x_2+0.15x_1x_2+0.69x_3}} \right)^{8.14}
\end{aligned}$$

From this equation it is evident that the values held by any of the predictor variables will have an impact on the size of the effect that changing any of the other predictor variables has on $P(Y > 0)$. As an example, Table 4.2 shows how $P(Y > 0)$ changes when x_1 increases from 0 to 1 for different x_2 and x_3 values:

Table 4.2 shows that the relationship between susceptibility to peer influence, self-control, peer delinquency, and the likelihood of delinquency in the next 12 months is not simple, but it can be calculated. It can therefore be incorporated into the computer simulation.

Table 4.2: Example values for Meldrum et al.'s negative binomial model

Self-control	Peer Delinquency	$\mathbf{P(Y>0)}$		% change
		SPI=0	SPI=1	
-1	-1	0.357	0.385	7.94
-1	0	0.576	0.611	6.01
-1	1	0.804	0.832	3.48
0	-1	0.322	0.391	21.37
0	0	0.531	0.618	16.20
0	1	0.765	0.837	9.47
1	-1	0.290	0.397	36.88
1	0	0.488	0.624	27.97
1	1	0.723	0.843	16.51

4.1.4.1 An Alternative Relationship

Although the negative binomial model was derived from empirical data, it is not the only function that could be put forward as a possible explanation for how morality, self-control, criminogenic exposure and individual propensity for crime are linked.

Section 4.1.1 explored the work carried out by Wikström on the effects of exposure to criminogenic settings on crime using situational action theory. Wikström defines crime propensity as being composed of a person's level of morality and their ability to exercise self-control. In his own research, he uses a measure for propensity that is a simple sum of these two variables converted into z-scores, so

$$\text{Propensity} = \text{Morality} + \text{Self-Control}$$

where Morality and Self-Control are calculated by coding the responses to a questionnaire and then converting these totals to z-scores (Wikström, 2009a). So far we have used susceptibility to peer influence as a proxy to represent morality; if this proxy is kept, then Wikström's equation suggests that we could simply put $p_i(t) = x_1 - x_2$ into the model instead of the negative binomial equation (where $p_i(t)$ represents the propensity of person i at time t). The sign for the self-control variable is negative because it is assumed that higher self-control reduces crime propensity.

However, such an equation does not provide any scope for including the influence of exposure to criminogenic settings on how propensity for crime develops. How can criminogenic influences be incorporated?

An answer comes from the work undertaken by Gino et al. (2011), which was discussed in Section 2.2.1. In this paper the authors explored the effects that reducing an individual's capacity to exercise self-control had on their moral behaviour, and they discovered that when people are repeatedly exposed to criminalising moral contexts, a person's self-control reserves become depleted. Further to this, when a person with a low capacity to exercise self-control is exposed to criminalising moral contexts, this does affect their moral behaviour. Consequently, from Gino et al.'s research it can be concluded that following repeated exposure to criminalising moral contexts, an individual with a high capacity to exercise self-control will, eventually, also see their moral behaviour altered.

These ideas can be combined to derive an alternative equation to the negative binomial one, building upon the following premises:

- Self-control (x_2) is immutable;
- Susceptibility to peer influence (x_1) can be used as a proxy variable for an individual's base level of morality;
- When an individual is exposed to a criminogenic setting, their morality level is altered from its base level;
- The extent to which an individual's morality is affected by their criminogenic exposure (x_3) is determined by their level of self-control, where high levels of self-control reduce the influence of criminogenic exposure on morality;
- An individual's propensity for crime is then the sum of their self-control and their current level of morality.

Bringing this together, one possible expression for person i's morality at time t could be:

$$m_i(t) = x_1 + \theta x_3 e^{-\gamma x_2}$$

where x_1 (susceptibility to peer influence) and x_2 (self-control) are independent random variables distributed $N(0,1)$, and x_3 is the z-score derived from the criminogenic exposure function (all as defined as in the negative binomial model), and θ and γ are model parameters[4]. Then, as in Wikström (2009a), person i's propensity for crime at time t would be:

$$p_i(t) = m_i(t) - x_2$$

This equation provides an alternative credible way to incorporate the relationship between morality, self-control, criminogenic exposure and propensity for crime into the computer simulation.

4.1.5 What environmental factors make a setting more or less likely to become criminogenic?

Section 4.1.2 examined the factors that cause people to be more or less likely to visit certain settings from the point of view of selection — that is, what makes someone choose to go to one setting over another. This was approached via the assumption that people are more likely to go to places that are closer to where they live, have a larger catchment area, and that are visited by like-minded people.

The importance of the presence of like-minded people leads to questions about *emergence*. Emergence is concerned with what causes a setting to be more likely to draw criminally-minded people to it so that it becomes a home to criminalising moral contexts. From the discussion about selection it is easy to see how criminogenic hubs can perpetuate: if a setting has a higher than average number of criminally-minded people who go there, more criminally-minded people will be attracted to it. But what environmental factors cause this process to start in the first place?

In Section 2.2.3 the hypothesis was put forward that a criminogenic moral context is

[4]Many other equations satisfying these premises could also be derived; this is simply one example

more likely to be found in a setting with low levels of collective efficacy. Collective efficacy is a concept introduced by Sampson et al. (1997) in a paper in which the authors argued that neighbourhoods in Chicago with higher collective efficacy would be likely to experience less neighbourhood violence. The authors measured collective efficacy by means of a neighbourhood survey that looked at two aspects of a neighbourhood: its levels of informal social control (such as whether local people would intervene if someone were spray-painting graffiti on walls), and its levels of social cohesion (for instance whether people trust their neighbours and consider the community to be close). Using this definition they went on to show that low levels of collective efficacy were correlated with higher levels of violence, which suggests that low collective efficacy does indeed make a setting more criminogenic.

However it should not be supposed that the findings from a study conducted in 1990s Chicago can be directly transferred to the 21st century UK context. Thankfully, more recent UK-based data is available. The Peterborough Adolescent and Young Adult Development Study (PADS+) is a longitudinal study that was set up to study the criminal behaviour of adolescents in Peterborough, Cambridgeshire (PADS+, 2015). One of the main focuses of the PADS+ project is in understanding the effect that the environment has on the criminal propensities of young people, including to what extent low collective efficacy in a setting affects the people in the study (Wikström, 2011a). Importantly, this study examines the effects of settings with low collective efficacy on crime *propensity*, not *actual* crime; this ensures that the focus remains on the development of an individual's morality, and not on the "action process" which causes an individual to actually commit an act of crime at any particular time.

Wikström (2011a) uses the same measure for collective efficacy as Sampson et al. (1997), and finds conclusively that "the weaker the collective efficacy of a young person's family, school and neighbourhood environments, the more likely it is that he or she will have a stronger crime propensity" (Wikström, 2011a, p. 113). As with his previous research, for this study Wikström defines crime propensity as comprising morality and self-control, and he notes that settings with low collective efficacy have a much stronger effect on morality than they do on self-control. This supports the discussion in Section 2.2.1 concerning the psychology of morality and self-control, in which it was concluded that self-control, as a largely genetic trait, is more immutable than morality.

Wikström further notes that low collective efficacy does not fully capture the importance of peer delinquency on the development of an individual's crime propensity, and that when this is included in the model it is peer delinquency that has the greater effect (though the effect of low collective efficacy is still significant) (2011a, p. 116). This finding accords with earlier discussions about the importance of peers on the development of a person's criminal propensity, and will be captured in the criminality development model by ensuring that a setting's criminogenity is determined by the criminal propensities of the people who go there.

How then to incorporate the effects of low collective efficacy in the computer simulation? There are two possible mechanisms through which low collective efficacy could cause a setting to become criminogenic: either through selection, where criminally-minded people are attracted by low collective efficacy, or else by boosting the effect that criminally-minded people have when they are present at a setting. To date there has been no research conducted to distinguish between the two possible mechanisms, so both will be explored in the computer simulation.

4.1.6 How are environmental factors to be measured?

The importance of the environment in the IVEE model has been made clear in the preceding sections, with many different environmental factors having influence at different stages of the process. The computer simulation therefore cannot work with simulated people alone — it must also be given a location in which to operate. This can be done in two different ways. The first possibility is that, as with the simulated people, the environment that is input into the model can be an entirely fictitious one. The advantage of this is that it allows for all the environmental factors to be controlled, which will facilitate later analysis and make it easier to draw conclusions as to the impact of changing these environmental factors. However a fictitious environment may lack realism and lead the model to generate implausible results.

Alternatively, the computer simulation can be located in a real UK town. This would add considerably to the simulation's authenticity, but would require accurate information about the chosen town to be collected for input into the simulation. While this may be a simple task for some attributes and settings, such as identifying the size and location of schools, it may be far more time consuming to collect this information for others, such as identifying the size of every local employer, and calculating the collective efficacy of every neighbourhood. Forcing the computer simulation to be based on a real town also constrains the model and limits the amount of manipulation of environmental parameters that can take place.

It should be recalled that the purpose of the computer simulation is to better understand the impact that changing different factors will have on the criminality development process. The simulation does not therefore require the level of realism that a predictive model would. It is therefore proposed that the computer simulation should operate in a modified version of a UK town: real locations will be used where they can be easily identified, but it will not be required for all attributes associated with the locations to be recorded accurately. This allows the model to operate in an environment that should provide the necessary level of realism for the simulation to generate credible results, but without requiring an extensive period of on-the-ground data collection that would not enhance the model's overall value. As this modified version of a real town is ultimately fictitious, all control of the environmental factors remains with the modeller.

The town chosen to provide the basis for the environment to be used in the model is Peterborough, a settlement with a population of approximately 115,000 that has considerable social and ethnic diversity (Wikström et al., 2010). Peterborough is a logical choice for the model's environment as much of the UK-based research that the model draws on was conducted as part of the Peterborough Adolescent and

Young Adult Development Study (PADS+) project.

The following environmental factors have been identified in previous sections as having a role to play in the process of criminal propensity development, and therefore will require inputting into the computer simulation for key settings in Peterborough:

- Type of setting
- Location of setting
- Size of setting
- Collective efficacy of setting

These first three attributes can be easily estimated for key locations in Peterborough by conducting a web search. Collective efficacy is more subjective and requires the use of a large survey. However as precise values are not necessary for the model to serve its purpose, the collective efficacy values will not be estimated, and instead will be controlled by the modeller.

4.2 Description of the Model

4.2.1 Overview

This section provides an overview of the criminality development model, and uses an example from epidemiology to illustrate the modelling method and show how the different levels in IVEE can be brought together.

As discussed in Chapter 3, the modelling technique chosen to represent the criminality development process is an individual-level state-transition model (STM). STMs are commonly used in epidemiology to describe the spread of infectious diseases, with the simplest version being the basic SIR model (Keeling and Rohani, 2008). The SIR model represents the process of infection, where a person can be in one of three states: “susceptible”, “infectious”, or “recovered”. The arrangement of these states is illustrated in Figure 4.1.

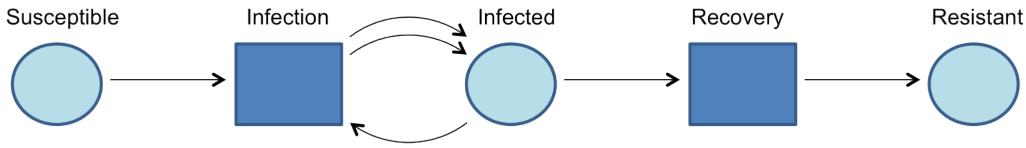


Figure 4.1: Basic SIR model

In this diagram, the circles represent *states* and the boxes represent *transitions* between the different states. Every transition has an equal number of inputs and outputs, so in the process of "infection" a susceptible person becomes exposed to an infected person, and the output of that process is two infected people. The process of "recovery" is simpler, just requiring one infectious person as input and one recovered (and in this example immune) person as output.

The diagram in Figure 4.1 is called a Petri net. A Petri net is a graph which has two categories of vertices: states and transitions. They can be used to describe many different types of complex system, such as chemical reactions or predator-prey relationships in an ecosystem (Baez and Biamonte, 2012, p. 9). They can be deterministic, whereby anything going in to a transition comes out the other side, or they can be stochastic, whereby each transition has a rate constant describing the rate at which the input state transforms into the output state. As the criminal propensity development model is to be a deterministic individual-level STM, it should thus be possible to illustrate it as a Petri net.

In order to do this let us first consider a simplified version of IVEE, which ignores the emergence of criminogenic settings and looks solely at a vulnerable person and their exposure to criminogenic settings. When this is illustrated as a Petri net, it would look like Figure 4.2. In this Petri net there is a transition called "Exposure" that causes a *Criminogenic Setting* to have an effect on a *Neutral Person* and turn them into a *Criminally-Minded Person*.

Similarly, the emergence transition can also be illustrated as its own Petri net. While exposure is concerned with what effect a setting has on a person, emergence is about what effect a person has on a setting. The emergence Petri net would therefore see a *Neutral Setting* turn into a *Criminogenic Setting*, through the presence of a

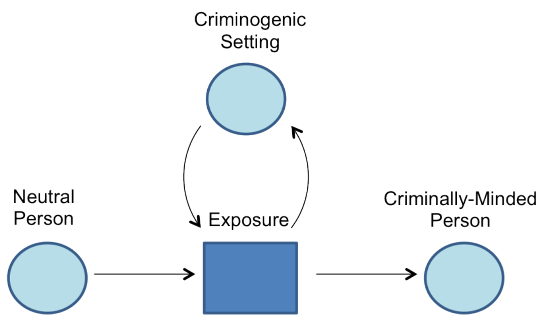


Figure 4.2: Simplified IVEE Petri net for exposure

Criminally-Minded Person. This is depicted in Figure 4.3.

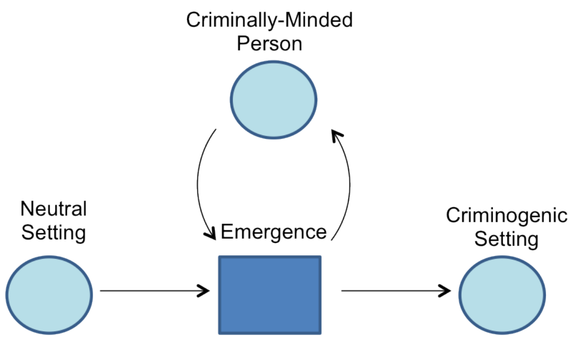


Figure 4.3: Simplified IVEE Petri net for emergence

By combining the two, an initial basic Petri net describing the criminality development process according to the IVEE model can be illustrated. This is shown in Figure 4.4.

Figure 4.4 is a way of illustrating the overall IVEE framework for criminal propensity development in the form of a mathematical model. As previously discussed, all models are simplifications of reality, however the basic Petri net on its own is too simple to explain the entire criminality development process. In order to create a simulation that mimics the process, it is necessary to look in more detail at the emergence and exposure transitions and ensure that the way they are defined reflects reality, by drawing on the data and statistical models discussed throughout this chapter.

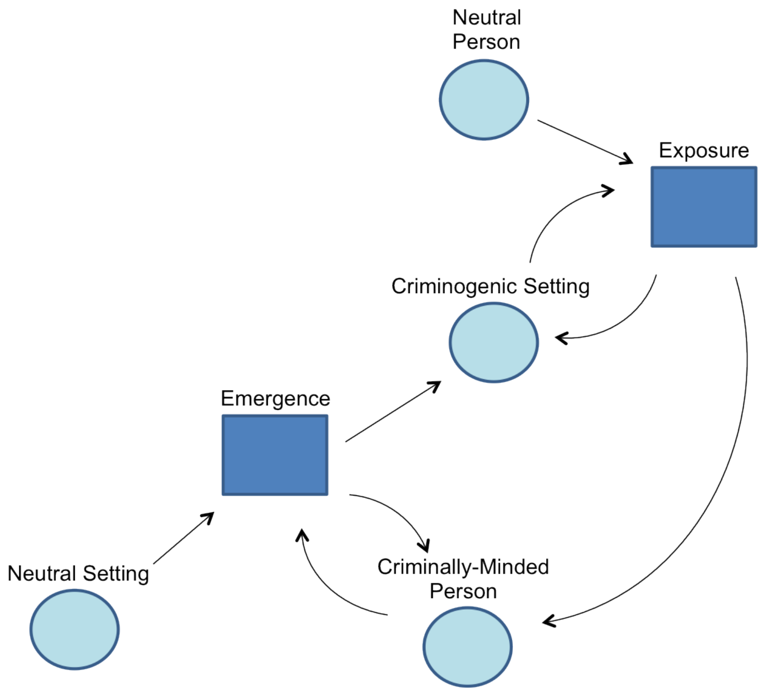


Figure 4.4: Basic IVEE Petri net

4.2.2 The Emergence Transition

The emergence transition occurs when a setting forms a significant part of a criminally-minded person's activity field — that is for any setting j for which $f_{ijk}(t) > \tau_1$ for some time threshold τ_1, where person i has a significant propensity p for some criminal behaviour (so $p_i(t) > \varepsilon$ for some propensity threshold ε). The time and propensity thresholds τ_1 and ε could hold a variety of values; the impact of changing these thresholds in terms of the behaviour of the model and the real world implications will be explored in Chapter 5.

After the emergence transition the criminogenity of a setting j at time t is defined to be:

$$c_j(t) = \frac{\omega_j}{n}\left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t)>\tau_1 \\ \& \ p_i(t)>\varepsilon}} p_i(t)\right)$$

where $p_i(t)$ is the propensity of person i to some crime at time t, n is the number of people i such that $f_{ijk}(t) > \tau_1$, and ω_j is the collective efficacy coefficient of the setting (where a high value for ω_j indicates a setting with very little collective efficacy). Thus after the emergence transition the criminogenity of the setting for each type of criminal behaviour becomes the mean of the propensities of all people spending a significant amount of time at that setting, multiplied by the collective efficacy coefficient.

4.2.3 The Exposure Transition

The exposure transition occurs when person i spends a non-zero amount of time in a criminogenic setting j. The exposure transition is defined to be the way the three variables of cognitive susceptibility, criminogenic influence, and criminal propensity (comprising morality and self-control) interact. There are a number of possible candidates for this function, such as simple linear functions or probability functions like the one derived from the negative binomial distribution discussed in Section 4.1.4. Chapter 5 will explore how using different functions for the exposure transition affects the way the model behaves, including the impact of incorporating thresholds similar to τ_1 and ε.

A complete description of the criminal propensity development model is at Appendix A.

4.3 Application to Radicalisation

So far this chapter has examined how the IVEE framework can be used to construct a mathematical model and computer simulation describing how criminal propensity develops. However recall that the research question this thesis aims to answer requires a comparison between the process of criminal propensity development and radicalisation. Constructing this model is therefore only half the answer: an equivalent model must be constructed for radicalisation.

In Chapter 2 three potential differences were identified between radicalisation and the development of a propensity for crime more generally. These differences were in the severity of the crime that an individual has the propensity to commit, the level of morality required, and the rarity of radicalising moral contexts.

The first two of these factors are easy to incorporate, as they simply require a change in how the output from the model should be interpreted. For instance, an individual may be considered to have the propensity for some types of crime if, after the simulation has been run, they have mid-level morality and low levels of self-control. However for an individual to count as radicalised, they would need to have a level of morality sufficient for them to consider very severe crimes such as homicide or significant property damage to be acceptable.

Incorporating the final aspect — the rarity of radicalising settings — will require a change to the emergence transition to make it less likely that radicalising moral contexts appear. There are a number of ways that this could be achieved, such as increasing the thresholds ε and τ_1. The specifics of all the alterations that would need to be made to the model so that it represents the radicalisation process instead of the criminality development process will be explored in Chapter 6.

Chapter 5

Testing the Model

The previous chapter proposed how a model describing the criminality development process could be constructed using the IVEE theoretical framework and a computer simulation built. However, the knowledge built up by social science researchers on how criminality develops is still incomplete, and there are a great many elements of the model that could be changed. In this chapter, the model will be tested by using different values and functions in some of its component parts. The simulation will then be run for these different versions of the model and the outputs compared in order to understand the effects that changing each element of the model has on the system as a whole.

There are several broad areas where changes could be made. Changes can be made to the inputs: the environment and the people. How does altering the locations or attributes of key settings affect the way the model behaves? How about a different ethnic, religious or age mix of people?

Changes could be made to the selection mechanisms: how do the people and the environment come together? How much weight should be given to the attractiveness of settings to different people, and how much to the cost of getting there?

Changes can also be made to the emergence and exposure transitions themselves. For emergence, one can introduce thresholds for how long an individual must spend at a setting or what propensity they need to have to affect the setting. For exposure, one can change the function that measures each person's level of exposure to criminogenic settings, or even the whole function connecting this with their levels of self-control and morality. What impact do these changes have on the model as a whole?

This chapter will explore the impact that these alterations to the model have on how propensity spreads and changes across the people in the model, to determine how sensitive or stable the model is. This will enable the workings of the model in its current form to be fully understood before it is then converted into a model describing the radicalisation process, which will be explained in Chapter 6. But first, a default version of the model will be defined and its behaviour analysed.

5.1 Default Version of the Model

5.1.1 Model Description

Due to the number of elements of the model that can potentially be altered, a default setting for the model needs to be defined to allow comparisons to be made when these settings are changed. The functions, inputs and parameters making up the default version of the model are described below. A full description of the model is also at Appendix A.

5.1.1.1 Activity Field Generation

Section 4.1.2.2 showed that an activity field for person i can be estimated using the function

$$f_{ijk} = A_{ik} Q_{ik} W_{ij}^{\alpha} e^{-\beta c_{ij}}$$

where k is the type of setting that j is, Q_{ik} represents the amount of time person i spends in settings of type k, W_{ij} represents the attractiveness of setting j to person i, c_{ij} represents the cost to person i of going to setting j, A_{ik} is a scaling factor, and α and β are model parameters, which will be set to 1 in the default version of the model. Note that the activity fields are recalculated every time-step, as some of these variables will change over time.

The variable Q_{ik} is defined using the assumptions stated in Section 4.1.2.2 regarding how many hours people of certain socio-demographic characteristics are expected to spend in certain locations each week. A look-up table showing the values for Q_{ik} is at Appendix B.

The attractiveness factor, W_{ij}, is a composite variable that is a function of the size of setting j (which we shall write as $|j|$) and j's similarity to person i. The similarity of person i to setting j was briefly discussed in Section 4.1.2.2, but here it requires a complete definition.

Let us define a function $Dx_{ij}(t)$ to be the difference in attribute x between person i and the mean value of that attribute among everyone visiting setting j. So for example, suppose the attribute is religion (*rel*) and we code it as 0 for Christian and 1 for Muslim. Then

$$Drel_{ij}(t) = \left| rel_i(t-1) - \sum_{\substack{\forall i \text{ s. t.} \\ f_{ijk}(t-1)>0}} \frac{rel_i(t-1)}{n} \right|$$

where n is the number of people such that $f_{ijk}(t-1) > 0$. Similarly, for the attribute propensity (p):

$$Dp_{ij}(t) = \left| p_i(t-1) - \sum_{\substack{\forall i \text{ s. t.} \\ f_{ijk}(t-1)>0}} \frac{p_i(t-1)}{n} \right|$$

As propensity (as defined in the exposure transition below) and religion both hold values in the interval $[0,1]$, it follows that $Drel, Dp \in [0,1]$. However other attributes — self-control, susceptibility to peer influence, and age — take values in different intervals, or are unbounded. This poses more of a problem when defining the Dx function for these attributes, as we wish for all attributes to have an equal weighting when they are combined in the similarity function. We therefore need to ensure that Dx is defined so that for each attribute is maps to the same interval — for instance $[0,1]$. How to determine what these functions should be?

Self-control (*sc*) and susceptibility to peer influence (*spi*) are random variables distributed $N(0,1)$, and can therefore hold any real value. For these attributes we therefore require Dx to be a mapping $Dx : \mathbb{R}^2 \to [0,1]$ so that for all $(a,b) \in \mathbb{R}^2$, when $a = b$ this gives $Dx = 0$. The function should increase as $|a-b|$ increases. A starting point for finding an appropriate function can be taken from the Box-Muller transformation, which tranforms two variables $x_1, x_2 \sim U(0,1)$ into two variables $z_1, z_2 \sim N(0,1)$. The inverse of the Box-Muller transformation is:

$$x_1 = e^{-\frac{(z_1^2+z_2^2)}{2}} \text{ and } x_2 = \frac{1}{2\pi} \arctan\left(\frac{z_2}{z_1}\right)$$

This provides us with two potential candidates for the function *Dsc* that would meet the necessary criteria:

$$Dsc_{ij}(t) = 1 - e^{-\zeta|sc_i(t-1)-sc_j(t-1)|}, \text{ or}$$

$$Dsc_{ij}(t) = \frac{1}{2\pi} \arctan \zeta \left|sc_i(t-1) - sc_j(t-1)\right|$$

where $sc_i(t-1)$ is the self-control level of i at time $t-1$ and $sc_j(t-1)$ is the mean average of sc_i for all i visiting setting j at time $t-1$. The parameter ζ can hold any positive value. Any of these options would be equally suitable from a logical perspective, but as the second function is a trigonometric function it is more difficult to implement in the computer simulation, as different versions of the arctan function may output to different intervals. Therefore, to avoid ambiguity, the first function will be used for *Dsc* (and similarly for *Dspi*), with a value of $\zeta = 1$.

The final Dx function that needs to be defined is for age. The bounds of age depend on how it is coded; for the default version of the model age shall be coded as in Table 5.1, putting $age_i \in [0,5]$.

A suitable difference function for age would therefore be:

$$Dage_{ij}(t) = \frac{1}{5} \left| age_i(t-1) - \sum_{\substack{\forall i \text{ s. t.} \\ f_{ijk}(t-1)>0}} \frac{age_i(t-1)}{n} \right|$$

Table 5.1: Age coding scheme

Age	Code
Under 16	0
16-18	1
19-23	2
24-30	3
31-40	4
Over 40	5

The overall difference function for all five attributes is therefore:

$$D_{ij}(t) = \frac{1}{5}\left(\eta_1 Drel_{ij}(t) + \eta_2 Dp_{ij}(t) + \eta_3 Dsc_{ij}(t) + \eta_4 Dspi_{ij}(t) + \eta_5 Dage_{ij}(t)\right)$$

where the η values enable different weighting to be given to each attribute. For the default version of the model these will all be set to 1, so that all attributes have the same weight.

To turn this into a function determining similarity the scale should be reversed, so that 0 implies minimal similarity and 1 is identity. Therefore the similarity function is $S_{ij}(t) = 1 - D_{ij}(t)$. The attractiveness variable in the default version of the model is then $W_{ij}(t) = S_{ij}(t)|j|$.

The cost c_{ij} of person i going to setting j is a simple measure of the distance as the crow flies from person i's home to the location of setting j.

The scaling factor is

$$A_{ik} = \frac{1}{\sum_{l \in J_k} W_{il}^{\alpha} e^{-\beta c_{il}}}$$

where the set J_k in the summation is the set comprising all settings of type $k \in K$ where, as previously stated, K is such that the family $\{J_k\}_{k \in K}$ is a partition of J. This scaling factor ensures that $\sum_{j \in J_k} f_{ijk} = Q_{ik}$.

Bringing all this together the equation for activity field generation in the default model is:

$$f_{ijk}(t) = \frac{Q_{ik}(t) S_{ij}(t)|j|e^{-c_{ij}}}{\sum_{l \in J_k} S_{il}(t)|l|e^{-c_{il}}}$$

5.1.1.2 Emergence Transition

The emergence transition for the default version of the model is as defined in Section 4.2.2 with the values for τ_1 and ε equal to zero. Therefore, following the emergence transition, the criminogenity level of setting j at time t is:

$$c_j(t) = \frac{\omega_j}{n} \left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t)>0 \\ \& \ p_i(t)>0}} p_i(t) \right)$$

5.1.1.3 Exposure Transition

The exposure transition for the default version of the model shall be as per the negative binomial model described in Section 4.1.4. So, after the exposure transition, i's propensity for criminal behaviour is:

$$p_i(t) = 1 - \left(\frac{1}{1 + 0.1228 e^{-0.23+0.25x_1-0.13x_2+0.15x_1x_2+0.69x_3}} \right)^{8.14}$$

where x_1 is i's susceptibility to peer influence, x_2 is i's self-control, and x_3 is a measure of the amount of exposure to criminogenic settings that person i has had. In the original version of the negative binomial regression model as put forward by Meldrum et al. (2013) x_3 is peer delinquency, which is a slightly different measure, but for the default simulation x_3 will be defined as the mean average of the criminogenity of each setting visited by person i that time step. All the x_i values are z-scores, which is simple for x_1 and x_2 as they are randomly generated from a normal distribution (as discussed in the following subsection), but x_3 requires a transformation before it can be used in the negative binomial equation. The value of μ for this transformation is taken to be $\mathrm{E}(p_i(t)) = 0.5314549$, but due to the complexity of the negative binomial function the variance cannot be calculated analytically. This variance will instead be approximated using the sample variance from some trial simulations, which was calculated to be approximately 0.04.

5.1.1.4 Geographical Input

The geographical input to the model is a simplified version of the UK city of Peterborough. The settings in Peterborough that are included in the geographical input are 11 schools, 2 higher education sites, the 8 largest local employers, 7 mosques, the 8 largest churches, the 6 largest shopping centres (high streets), 5 leisure centres, and 8 youth clubs. In addition, every person in the model has a home location (see below). For the default version of the model all settings have a collective efficacy coefficient equal to 1.

For a list of the names, locations and sizes of all settings input into the model see Appendix C.

5.1.1.5 People Input

The default people input to the simulation consists of 100 people whose home locations are distributed evenly across the geographical area. There is an even split across gender, religion (Christian, Muslim or none), and occupation (employed, unemployed or studying). The ages of the people at the start of the simulation are evenly divided between the ages of 14 and 30, with the only constraint being that those aged 16 or below all have occupation “student”. Further details of the distribution of attributes across the simulated population are in Appendix C. Susceptibility to peer influence (SPI) is generated randomly from a normal distribution with variance 1 and mean varying according to age and gender, as was illustrated in Table 4.1. Self-control is generated randomly (and independently of SPI) from a normal distribution with mean 0 and variance 1. The starting propensity of all people is set to be 0.5.

5.1.1.6 Time

One time-step in the simulation is defined to be one week. There are two parameters which are functions of time alone: the first is a person’s susceptibility to peer influence (SPI) level when they are aged between 14 and 18, and the second is the selection quotient Q_{ik}. For i between the ages of 14 and 18, i's SPI reduces by 0.0095804 every time-step, in accordance with the findings of Steinberg and Monahan (2007) discussed in Section 4.1.3. The changes to Q_{ik} are step-changes which come after i reaches the age of 18, when they attend universities instead of schools, and after the age of 20 when they stop attending youth clubs. For more details see Appendix B.

5.1.1.7 Simulation Language

The programming language used to code the model was C++. This language was chosen because the structure of the model in terms of the states (people and settings) and transitions (exposure and emergence) lent itself well to an object-oriented language. C++ is a highly flexible language which has the added advantage of being very efficient as it does not include graphical packages or visual elements which would have been superfluous for this project (Stroustrup, 2007).

5.1.2 Model Behaviour

The default version of the simulation was run for 260 time-steps, representing a period of five years. The change in the mean of the propensity for crime of all people in the model over this time period is shown in Figure 5.1. This graph shows that the average propensity for crime initially rises sharply over approximately 20 time-steps, before then reducing slowly at a steady rate until $t = 208$. Between $t = 208$ and $t = 239$ propensity rises again very slightly, before finally becoming static.

However, the mean may not be the best way to understand how propensity for crime is changing, as there could be considerable variation in propensity across the 100 people in the model. The graph at Figure 5.2 shows how the propensity for crime of each of the 100 people has changed over this period, with snap-shots at t=5, 10, 26, 52, then every 52 time-steps after that. These graphs show that although all people in the simulation start with the same propensity for crime, once the simulation begins their propensities differ.

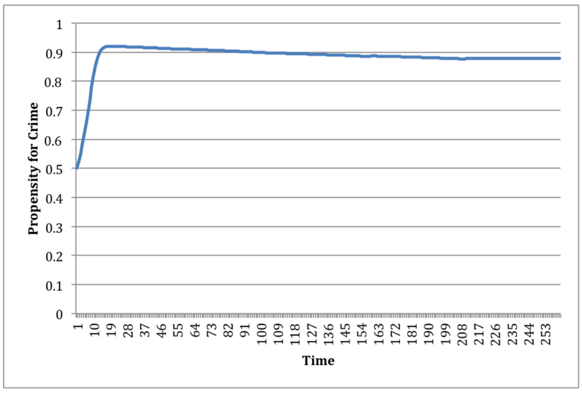


Figure 5.1: The mean average propensity for crime for all people over 260 time-steps.

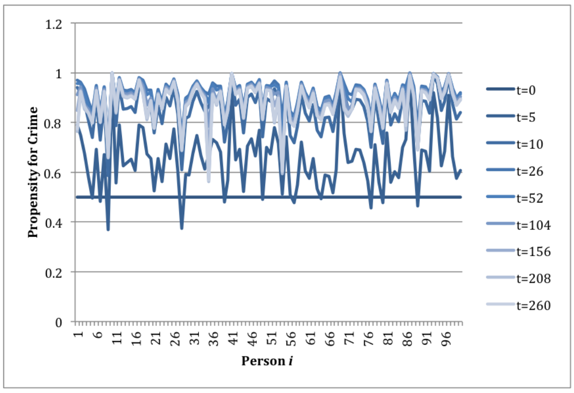
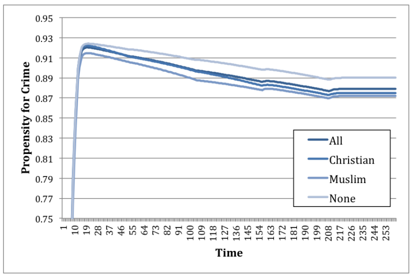


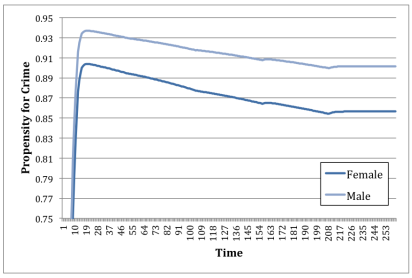
Figure 5.2: Crime propensity for all people at different times in the simulation.

There are a number of possible reasons why people starting with the same propensity for crime end up with different propensities by the end of the simulation. One of these reasons may be the socio-demographic groups to which each person belongs, as people from different groups have different settings in their activity fields. Graphs showing how the mean average of crime propensity changes for different socio-demographic groups are in Figures 5.3a, 5.3b, 5.3c and 5.3d.

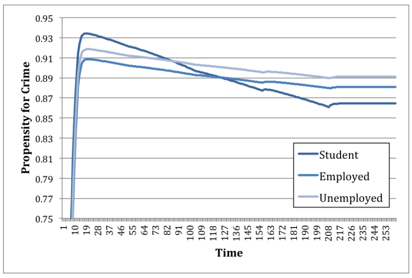
Figures 5.3a, 5.3b, and 5.3c show that the general pattern of change in propensity for crime over time is similar within socio-demographic groups, although some do have a higher mean propensity for crime than others. This difference is most striking in Figure 5.3b which separates the population by gender, and is likely due to the fact that females in the simulation are given a lower mean susceptibility to peer influence than males. In Figure 5.3c, the graph for the "Student" group has a greater negative gradient than the other groups, which is possibly due to the younger average age of



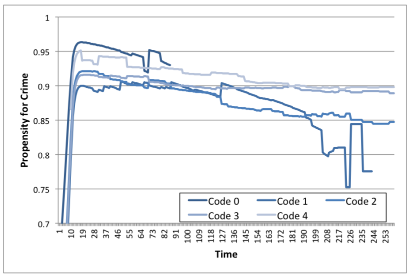
(a) By religion



(b) By gender



(c) By occupation



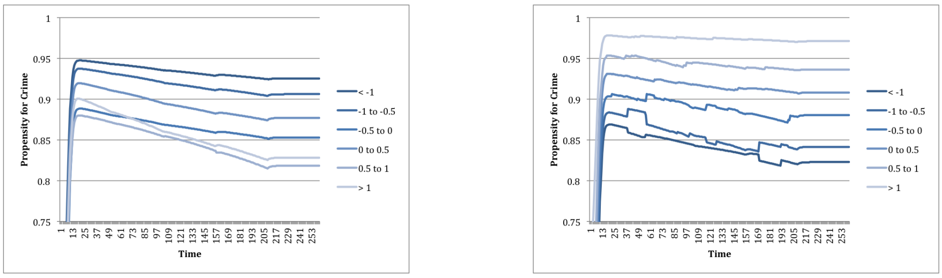
(d) By age

Figure 5.3: Mean propensity for crime by religion, gender, occupation and age code over 260 time-steps

people in the simulation classified as students, as all people with starting age 14-16 were designated students, and for these individuals their susceptibility to peer influence reduces until the age of 18.

The graph depicting the change in propensity for crime according to age cohort, Figure 5.3d, requires a more detailed explanation, as there are clear discontinuities in the mean average crime propensity among nearly all age groups. This feature is due to individuals changing age cohorts as they pass certain birthdays, with the discontinuities becoming more apparent when an age cohort has a very small number of members. The general decline in propensity for crime within the younger age cohorts in particular (except for the discontinuities) can be explained by the change in susceptibility to peer influence that happens during adolescence. Interestingly, this decline is also present in the older age cohorts (albeit to a lesser degree), where no individual change in susceptibility to peer influence takes place. It can therefore be surmised that the changes in the older age cohorts must be due to environmental factors — that is, that as people age they go to less criminogenic settings.

It is also important to examine how propensity for crime changes with individual



(a) By self-control **(b)** By SPI

Figure 5.4: Mean propensity for crime by self-control and susceptibility to peer influence over 260 time-steps

psychological factors (self-control and susceptibility to peer influence) in order to determine how influential these factors are when compared with socio-demographic and environmental factors. These graphs are shown in Figures 5.4a and 5.4b. Figure 5.4a, depicting propensity for crime according to self-control, shows that while those with the least self-control have the highest propensity for crime and those with higher levels of self-control have generally lower levels, this rule is not entirely consistent, and thus self-control must have a lesser impact on propensity for crime than other factors. However Figure 5.4b, showing propensity for crime according to susceptibility to peer influence, does have the consistent pattern that individuals with higher levels of susceptibility always have greater propensity for crime. As with the age cohort graph, the discontinuities in this graph are caused by individuals changing category during the simulation as their susceptibility to peer influence changes through adolescence. From these two graphs it can be supposed that susceptibility to peer influence has a greater impact on propensity for crime than self-control; this is supported by the relative weights of these factors in the negative binomial equation.

What then is the effect of geographical factors on propensity for crime? The map at Figure 5.5 shows the distribution of propensities for crime according to each person's home location and the criminogenity of each of the settings in Peterborough. There are no clear patterns visible in this map, suggesting that for this default version of the model the role of geography in the development of crime propensity is insignificant. However, the default version of the model as described in Section

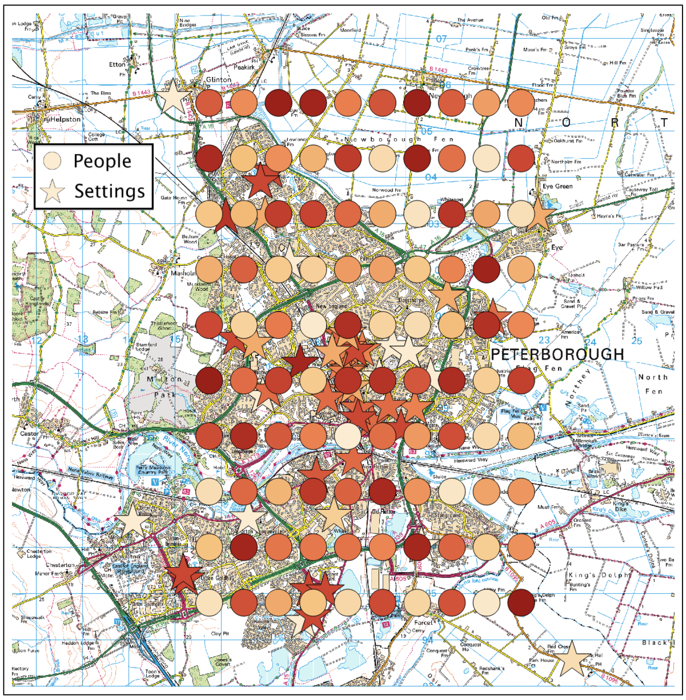


Figure 5.5: Distribution of propensity for crime across Peterborough. Darker colours indicate a higher propensity for crime.

5.1.1 has no thresholds for how long an individual has to spend in a setting for it to have an effect on them (or for them to have an effect on the setting). As the way activity fields are generated makes everybody in the model go to the same public places (such as high streets and leisure centres), even if only for a tiny fraction of time, this lack of thresholds leads to everybody's criminality levels affecting those of everybody else, and thus makes geography redundant. It would be expected that this map would show different results when the model is modified to include some thresholds.

5.2 Model variations

5.2.1 Changing the Time-step

The first change to the default model tests the model's general stability by changing the size of the time-step. For the default version of the model the time-step is set to be equal to one week, but if this time-step were changed the model should produce the same results.

In order to test this the model was modified so that one time-step represents one day, by altering the rate at which a person's susceptibility to peer influence changes with time for individuals aged between 14 and 18. No other parts of the model were changed, because no other model parameters are dependent on the size of the time-step. (While the activity fields are calculated based on the number of hours a person would be expected to spend in a certain location each week, this is then scaled so that the value of f_{ijk} is between 0 and 1, essentially representing the probability that a person spends time in a particular location. It is thus independent of the length of the time-step.)

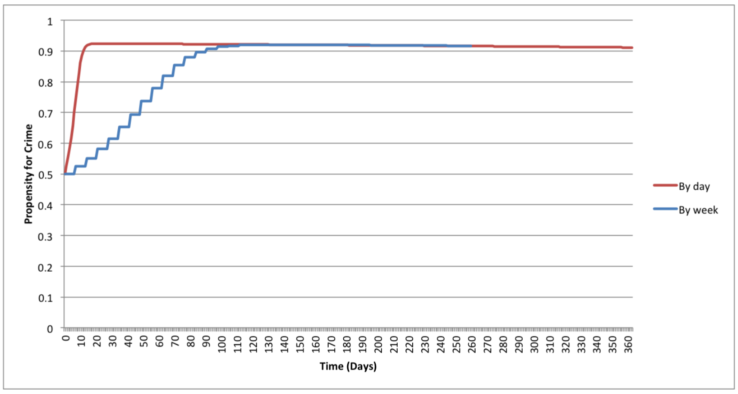


Figure 5.6: Average propensity level of 100 people for the first 365 days of the simulation, when the length of the time-step is one day and one week.

The model was run for 1825 time-steps, representing a period of 5 years, and the outputs compared with those of the original version. It was found that, as expected, the propensities of the people and the criminogenity levels of the settings were unchanged at the end of the simulation regardless of the length of time-step used. However, when the average propensity levels of all 100 people were compared over time, it was found that there were some differences between the two models at the start of the simulation (see Figure 5.6). In particular, there is a significant difference between the average propensities produced by the models over the first 100 days (100 time-steps for the "day" model, or 14 time-steps for the "week" model). However, when the average propensities for the first 14 time-steps of the "day" model are analysed, these closely resemble the average propensities of the first 14 time-steps of the "week" model. This suggests that the simulation takes approximately

14 time-steps before it stabilises, and therefore that outputs produced in the first 14 time-steps should be disregarded.

5.2.2 Changes to the Activity Field generation

The default version of the model calculates each person's activity field using the equation

$$f_{ijk}(t) = A_{ik}(t)Q_{ik}(t)W_{ij}(t)^{\alpha}e^{-\beta c_{ij}}$$

where α and β are equal to 1, and $W_{ij}(t) = S_{ij}(t)|j| = (1-D_{ij}(t))|j|$ where $D_{ij}(t)$ is the difference function defined in Section 5.1.1.

There are a multitude of changes that could be made to the way activity fields are generated, from the values used in the Q_{ik} look-up table to the way the cost c_{ij} of person i going to setting j is defined. However examining every possible way activity fields could be calculated would be both time-consuming and would fail to produce any further insight into answering this thesis' key research question. Nevertheless, some experimentation with the way activity fields are defined needs to be carried out in order to determine how sensitive the model is to changes in activity fields.

The parts of the equation that shall be changed in order to generate different activity fields are those that had no basis in prior research when they were defined in the default model: that is, the parameters α and β, and the way the attractiveness function W_{ij} is defined. In the default model the parameters α and β both hold the value of 1; in order to establish the impact of changing these values, tests will be conducted where the values of α and β are (separately) halved. This will have the effect of halving our measure of the importance of (respectively) the attractiveness of a setting and the cost of getting to a setting on the way activity fields are calculated. The impact of changing the way attractiveness is defined will be done by swapping the default definition of $W_{ij} = S_{ij}|j|$ for an alternative definition of $W_{ij} = |j|^{S_{ij}}$. Many alternative functions could be chosen for the way attractiveness is defined, and the reason for this particular choice is to make it a function sufficiently different from the default to be likely to have an impact on the activity fields, but that still has W_{ij} positively correlated with both $|j|$ and S_{ij}.

The following tests will therefore be conducted to explore the impact of changing these parameters on the activity fields:

	Default	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**
α	1	1	0.5	1	1	0.5
β	1	0.5	1	1	0.5	1
W_{ij}	$S_{ij}\|j\|$	$S_{ij}\|j\|$	$S_{ij}\|j\|$	$\|j\|^{S_{ij}}$	$\|j\|^{S_{ij}}$	$\|j\|^{S_{ij}}$

The simulation was run for these different model variants over 260 time-steps, and the resulting activity fields compared in terms of how they each change over time and the different places visited by a sample of 10 people covering a range of attributes and geographical locations.

5.2.2.1 Results

Before comparing the different model versions, first the activity fields for the sample of 10 people for the default version of the model were analysed to examine how they changed over time. Four of the 10 people experienced no change to their activity fields whatsoever; the remaining 6 experienced a combination of "hard-wired" changes (by which we mean changes that are built in to the simulation, such as moving from school to university at age 18, or no longer attending youth clubs from age 20) and "organic" changes created by the simulation itself (such as who the person's best friend is). For the default version of the model these hard-wired changes all occurred after a whole number of years (i.e. at t=52, 104, 156 or 208). The length of time that people spent at locations such as religious centres, high streets and leisure centres remained static throughout the simulation.

A similar analysis was conducted for the activity fields emerging from each of the test simulations. For Tests 1 and 2, the amount of time spent in religious centres, high streets and leisure centres (and youth clubs for under 20s) remained static, as it did for the default version of the model. However, for Tests 3, 4 and 5 (which use a different version of the W_{ij} function) there were small changes to the amount of time individuals spent in religious centres and high streets — although the amount of time spent in leisure centres remained static, which can be attributed to each being declared the same size in the settings input file.

For high streets, religious centres and youth clubs (where applicable), the proportion of time spent in each location varied across the different models. An example of this is shown in Figure 5.7, which illustrates how the proportion of time Person 65 spends in each mosque varies across the different models. This chart shows that when α is reduced (in Tests 2 and 5) the amount of time spent at Faidlan-e-Madina is lower but for Dar-es-Salaam is higher, while when β is reduced (in Tests 1 and 4) the opposite is true. This result is logical when the attributes of these two mosques are compared, as the Faidlan-e-Madina mosque is six times larger than Dar-es-Salaam, but Dar-es-Salaam is considerably closer to Person 65's home.

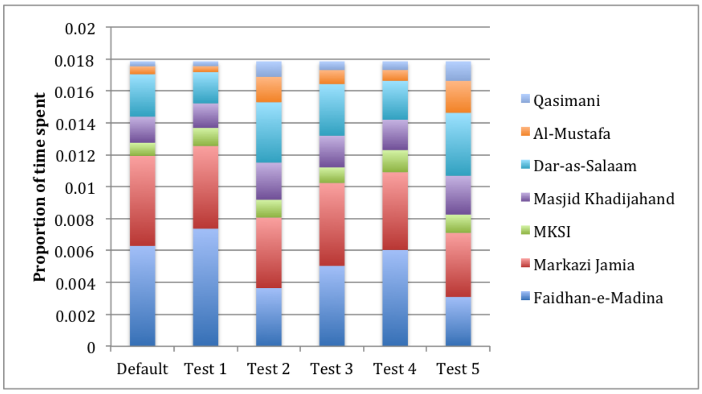


Figure 5.7: Differences in time spent at mosques for Person 65.

For workplaces and friends' residences the activity field generation equation has been engineered so that an individual will only spend time at a single location of that type, rather than spreading their time between several of them. The location of choice for each person is the one generating the highest value for $f_{ijk}(t)$ across all settings of that type. Exploring the activity fields of the sample of 10 people shows that which workplace or friend's residence is chosen for each person varies both through time within the same model and across different models. Table 5.3

illustrates this by listing all the different workplaces and friends' residences that appear in each person's activity fields at different times for different versions of the model.

A number of conclusions can be drawn from Table 5.3: firstly that some people in the model are more sensitive to change than others, both through time and across different model versions. For example Person 9 is immutable both in terms of his occupation and his choice of best friend across all times and all models; Person 87, by contrast, has at least four different best friends in all models, and in some models attends different schools as well.

The timings of the changes (not shown in the table) are mostly annual but not exclusively so, and as with the other differences the timings vary across model versions. The changes that are hard-wired into the model, such as moving from school to university at age 18 or no longer going to youth clubs from age 20, always take place annually at the predetermined time. But changes to a best friend or a workplace may occur in three different ways: annually in conjunction with a hard-wired change, annually when there is no other change, or at other times. By analysing the frequency of these three different types of changes in the different model versions we can assess which model variants produce more stability or more volatility to the activity fields. These frequencies are shown in Table 5.2 for the timing of changes to best friend.

Table 5.2 shows that the changes to best friend that take place annually in conjunc-

Table 5.2: Frequencies of different timings of changes to best friend

Model Variant	**Timing of change**			**Total**
	Annual with hard-wired	Annual with no other change	Not annual	
Default	6	4	0	10
Test 1	5	5	1	11
Test 2	5	4	0	9
Test 3	5	6	8	19
Test 4	5	5	8	18
Test 5	5	5	5	15

Table 5.3: Workplaces and friends' residences for 10 people over 260 time-steps

		Default	Test 1	Test 2	Test 3	Test 4	Test 5
Pers 9	**Friends** **Offices**	Person 8 Produce World	Person 8 Produce World	Person 8 Produce World	Person 8 Produce World	Person 8 Produce World	Person 8 Produce World
Pers 12	**Friends** **Offices**	Person 6 Indesit Company	Person 6 Indesit Company	Person 6 Indesit Company	Persons 3, 6 Indesit Company	Persons 6 & 24 Indesit Company British Sugar	Person 6 Indesit Company
Pers 21	**Friends** **Offices**	Persons 20 & 30 British Sugar	Person 30 British Sugar	Person 30 British Sugar	Persons 15 & 30 British Sugar	Persons 20 & 30 British Sugar	Persons 30 & 33 British Sugar
Pers 34	**Friends** **Schools**	Pers 35, 36 & 68 T. Deacon Acad. Peterborough Uni	Pers 35, 36 & 68 T. Deacon Acad. Peterborough Uni	Persons 35 & 43 Kings School Peterborough Uni	Pers 35, 36, 37, 43 Kings School Peterborough Uni	Pers 35, 36, 68, 69 T. Deacon Acad. Peterborough Uni	Pers 28, 35 & 43 Kings School Peterborough Uni
Pers 43	**Friends** **Offices**	Person 44 N/A (unemployed)	Person 44 N/A	Person 44 N/A	Person 44 N/A	Person 44 N/A	Person 44 N/A
Pers 56	**Friends** **Schools**	Persons 38 & 47 Peterborough Uni	Persons 38 & 47 Peterborough Uni	Persons 38 & 47 Peterborough Uni	Persons 38 & 47 Peterborough Uni	Persons 38 & 47 Peterborough Uni	Persons 38 & 47 Peterborough Uni
Pers 65	**Friends** **Schools**	Persons 53 & 98 Peterborough Uni	Persons 53 & 98 Peterborough Uni	Pers 53, 56 & 74 Peterborough Uni	Pers 41, 53, 56, 74 Peterborough Uni	Pers 53, 56 & 98 Peterborough Uni	Pers 53, 56 & 74 Peterborough Uni
Pers 78	**Friends** **Offices**	Person 66 Interecruit Ltd	Persons 77 & 89 Perkins Engines	Person 66 Interecruit Ltd	Persons 66 & 89 Interecruit Ltd Vital Recruitment	Pers 66, 77 & 99 Perkins Engines Interecruit Ltd	Persons 66 & 77 Interecruit Ltd
Pers 87	**Friends** **Schools**	Pers 69, 74, 86, 98 T. Deacon Acad. Peterborough Uni	74, 85, 86, 98 T. Deacon Acad. Voyager Acad. Peterborough Uni	69, 74, 86, 98 T. Deacon Acad. Peterborough Uni	69, 85, 86, 98 T. Deacon Acad. K. Stimpson Sch. Peterborough Uni	68, 70, 74, 86, 98 T. Deacon Acad. K. Stimpson Sch. Peterborough Uni	53, 69, 70, 74, 86 T. Deacon Acad. Voyager Acad. Peterborough Uni
Pers 90	**Friends** **Offices**	Persons 72 & 81 Perkins Engines	Persons 72 & 81 Perkins Engines	Persons 72 & 81 Perkins Engines	Persons 72 & 81 Perkins Engines	Persons 72 & 81 Perkins Engines	Persons 72 & 81 Perkins Engines

tion with a hard-wired change are relatively stable across all the model versions. However there are significantly more non-annual changes to best friend for Tests 3, 4, and 5; these are the models that use $W_{ij} = |j|^{S_{ij}}$ as the attractiveness function. The table also shows that for Tests 2 and 5 — the tests which give a greater weighting to the cost of getting to a setting — there are relatively fewer of these non-annual changes, making the activity fields more stable. These two observations together suggest that way the attractiveness variable is defined and the weighting given to it in the activity field generation equation have the most significant impact on the volatility of a person's activity field.

5.2.3 Changes to the Settings input

As with activity field generation, the settings that are input to the computer simulation can be altered in a variety of different ways. These include adding or removing settings, changing the attributes associated with the settings (such as their size, collective efficacy coefficient or location), or even using an entirely different town as the basis for the model. However as the purpose of testing the model is to better understand the impact that different factors have on how it behaves, such a drastic alteration as changing the town would not enable such conclusions to easily be drawn. In order to understand the impact that changing the settings has on the model, changes should be made one at a time and their impact measured after each change by comparison with the default model.

There are two ways that the impact of changing the settings can be assessed: one is through comparing each person's activity field with that of the default model, and the other is through comparing the levels of each person's propensity for crime. The latter method has the disadvantage that the link between settings and crime propensity is indirect: changing the settings affects the activity field directly, which then affects crime propensity levels via the exposure transition. Greater insight will therefore be gained by comparing the activity fields of a sample of people, as was done in Section 5.2.2.

The tests for the impact of changing the settings will be conducted by altering the attributes of one of the five leisure centres. Leisure centres were chosen for these tests because all people have them in their activity fields, they are well spread out across the geographical area (see Figure 5.8), and the default version of the model has set all leisure centres to be the same size, which facilitates comparison when this is changed.

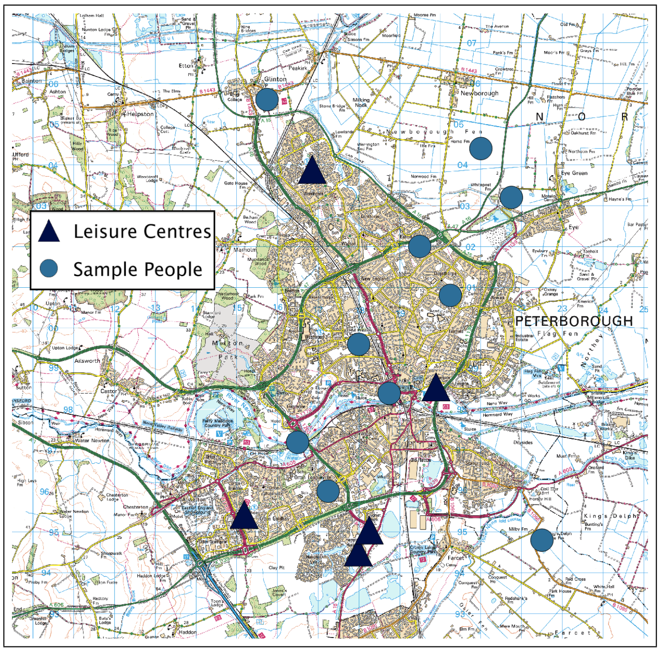


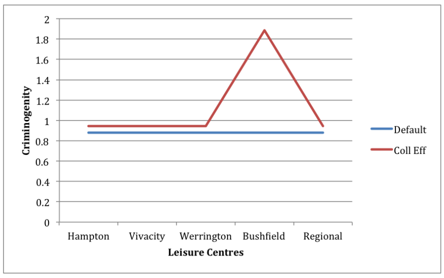
Figure 5.8: Location of leisure centres and the people in the test sample.

There will be four tests, each of which makes a different change to the Bushfield Leisure Centre, which is located in the south-west corner of Peterborough. These tests are as follows:

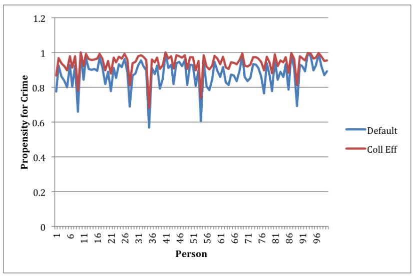
- Collective Efficacy Test: doubles the collective efficacy coefficient to 2 for this setting (keeping all other settings at 1);
- Size Test: doubles the setting size to 20,000 (keeping all other leisure centres at 10,000);
- Move Test: moves the setting 1km south and 1km west (i.e. further away from the centre of Peterborough and all the people in the sample);
- Removal Test: removing the setting entirely.

5.2.3.1 Results

The Collective Efficacy Test resulted in no change at all to the activity fields of each of the people in the sample. This might seem surprising, until it is recalled that the collective efficacy coefficient is only used in the model as part of the emergence transition, and is thus more likely to have an effect on the criminogenities of settings and propensities for crime than it is on activity fields. This supposition is indeed correct, as the graphs at Figure 5.9 show. It is particularly interesting to note from Figure 5.9a that increasing the collective efficacy coefficient of just one leisure centre affects the criminogenities of all leisure centres (albeit by a far smaller amount). Also noteworthy is the fact that while it might be logical for the change in collective efficacy coefficient to have an indirect effect on activity fields through its impact on criminogenities and propensities (which would then affect W_{ij}, the attractiveness variable), this appears not to be the case.



(a) Criminogenities



(b) Propensities

Figure 5.9: The effect of changing the collective efficacy factor for Bushfield Leisure Centre on the criminogenities of other leisure centres and the propensities for crime of all people

In the Size Test, for each of the people in the sample the amount of time they spent in the Bushfield Leisure Centre increased, as would be expected. The size of this increase varied from person to person, from a factor of 38% for Person 21 to 99.9% for Person 90. Concurrently, the proportion of time spent at the other leisure centres decreased for all people. The size of these decreases again varied from person to person, but was approximately equal across all leisure centres for each person (varying by less than 0.001% across leisure centres).

The Move Test saw the proportion of time people spent at the Bushfield Leisure

Centre decrease for all people in the sample, and increase for all the other leisure centres. The results for this test were very similar to that of the Size Test, in that the precise factors by which the proportions changed varied from person to person, but the overall pattern was the same. Time spent at the Bushfield Leisure Centre reduced by between 62.1% for Person 9 and 75.6% for Person 56, and the amount by which the time spent at other leisure centres increased varied between 0.02% for Person 90 and 51.2% for Person 21. As with the size test, the percentage increase in time spent at other leisure centres was approximately equal across the leisure centres.

The Removal Test again follows the pattern of the size and move tests. The amount of time spent at Bushfield Leisure Centre is reduced to zero in this test, and the amount of time spent at all other leisure centres increased. As with the other tests, the percentage increase in time spent at the other leisure centres is approximately equal across leisure centres, but varies significantly from person to person (from 0.03% for Person 90 to 81.5% for Person 21). This variation is unsurprising when the home locations of the people are taken into consideration: Person 90's home is a long distance from Bushfield Leisure Centre, so one would expect its closure to have little impact; conversely, Person 21 is one of the closest people to Bushfield Leisure Centre.

These results can be summarised in the graph at Figure 5.10, which shows how the proportion of time spent at the different leisure centres varies for Person 21 (as a typical example) under the different model variants.

5.2.4 Changes to the People input

There are a number of attributes associated with the people who are input into the model that could be altered to test how they affect the development of each person's propensity for crime. These include socio-demographic attributes such as peoples' ages, genders, religions, or occupation, and also individual factors such as their geographical locations. Changing the number of people in the model could also

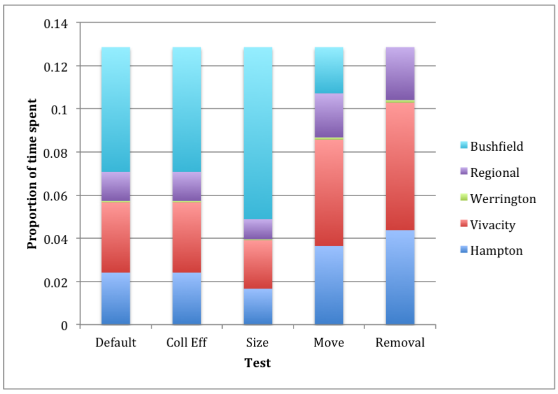


Figure 5.10: Proportion of time spent at leisure centres for Person 21.

have an effect on the development of crime propensity. This section consists of three tests on the impact of changing the people input: the first test explores the effects of changing their socio-demographic attributes (age, gender, religion and occupation), the second changes individual attributes (geographical location, self-control and susceptibility to peer influence), and the third increases the number of people in the model.

5.2.4.1 Test One: Socio-Demographic Factors

The default version of the model described in Section 5.1.1 uses a socially and demographically heterogeneous group of people, with many different combinations of gender, occupation, religion and age included. Test One compares the behaviour of the default model using the original heterogeneous people input with that of the default model using a far more homogeneous people input. The homogeneous people input comprises the following:

- Number and Location: 100 people distributed across Peterborough (as in Section 5.1.1 and Appendix C);
- Gender: All are male;
- Occupation: All are unemployed;
- Religion: All have no religion;
- Age: All are 21 years old at the start of the simulation;

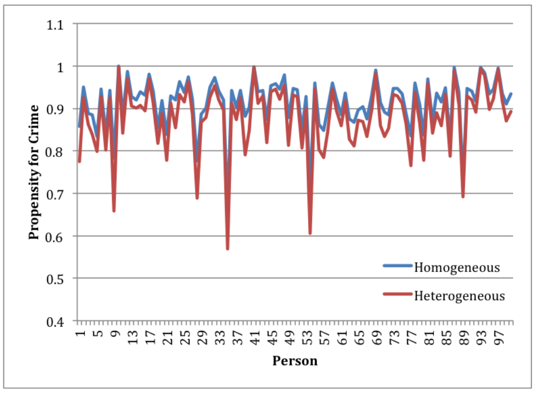


Figure 5.11: Propensities for crime after 260 time-steps for homogeneous and heterogeneous people inputs.

- Individual factors: Susceptibility to peer influence (SPI) and self-control are as in Section 5.1.1.
- Initialisation: All have an initial propensity of zero at time $t = 0$.

The two simulations were run for 260 time-steps and the resulting propensities for crime compared across all 100 people, as shown in Figure 5.11. The similarity between the two graphs is striking, suggesting that — for the default version of the model at least — the socio-demographic attributes of age, gender, religion and occupation have little bearing on each individual's propensity for crime. By process of elimination, each individual's propensity for crime must be more influenced by individual factors such as SPI, self-control, or geography than it is by socio-demographic factors. The propensity graph is slightly higher for the homogeneous input, but this can be explained by the fact that all people in the homogeneous input are male, and males have a slightly higher average SPI than females.

However it must be recalled that the default version of the model includes no thresholds for the length of time a person must spend in a setting for either exposure or emergence to happen. Therefore, because all people in the model spend a non-zero amount of time in public locations such as high streets and leisure centres, everybody's propensity for crime ultimately influences everybody else's. It is likely that when these thresholds are changed (in Sections 5.2.5 and 5.2.6 below) that socio-demographic factors may have more of an influence on each person's crime propensity development.

5.2.4.2 Test Two: Individual Factors

Test Two examines the effects of changing the individual factors associated with the people. There are three individual factors which could be altered: geographical location, self-control, and susceptibility to peer influence. In order to draw conclusions about the influence of each on the way the model behaves, these individual factors will be altered one at a time and the behaviour of the model compared with that of the default model.

The first stage of Test Two compares the default model using the homogeneous people input described in Test One with the default model using a similarly homogeneous people input file but with their geographical home locations switched around. For this latter version the pattern of individuals across the geographical area remains the same, but the specific people (uniquely identifiable by their susceptibility to peer influence and their self-control) are in different places. This change is achieved by rotating the people in the input file by 45 places, so that people who were originally on the edge of Peterborough are now in the centre (and vice versa).

After 260 time-steps the propensities of all people were plotted and compared with those from the default model, and these two graphs were found to be almost identical. Changing the geographical location of the individuals has thus been shown to have virtually no impact on propensities for the default version of the model. However, as was the case with Test One, the lack of thresholds in the exposure and emergence transitions of the default model is a possible reason for this, and this will be explored further in Sections 5.2.5 and 5.2.6.

The second stage of Test Two involves altering the self-control levels of some of the people in the model to see what impact this has on their propensities. Specifically, a test was run where the self-control level of one random person was increased by 1 (recall that self-control is a random variable distributed $N(0,1)$), and then a second test was run where the self-control levels of four people were increased by

1. Running the test in this way enabled conclusions to be drawn about to what extent an individual's self-control impacts on their own propensity and that of those around them, and the relative effects of this when more people undergo the change.

When Person 50's self-control was increased by 1 and all others kept the same, this had the effect of lowering Person 50's propensity at t=260 while all other people's propensity levels remained almost unchanged. When Persons 0, 25, 50 and 75 all had their self-control increased by 1 the propensity levels at t=260 for Person's 0, 50 and 75 were lower than for the default model, but perhaps surprisingly Person 25's propensity actually increased slightly. This can however be explained by the specific values of Person 25's susceptibility to peer influence (SPI) and self-control, as this person has an unusually high value for SPI (equal to 3.795) which when combined with a higher level of self-control actually increases his propensity for crime due to the interaction term in the negative binomial equation. This result is consistent with Meldrum et al.'s original finding that "the effect of susceptibility to peer influence on delinquency is stronger at higher values of self-control" (2013, p. 121). The effect of changing the self-control levels of Persons 0, 25, 50 and 75 had a slight impact on other people in the model, some of whom saw a very small reduction in their propensity levels at time t=260.

The third stage of Test Two consisted of the same test as the second stage but instead applied to SPI. Person 50's SPI level was reduced by 1, and in a separate test the SPI levels of Persons 0, 25, 50 and 75 were all reduced by 1. When only Person 50's SPI level was reduced by 1 their propensity at t=260 was lower, although by a smaller margin than when their self-control was increased by 1. This may initially seem surprising, as in the negative binomial equation greater weight is given to SPI than self-control. However it illustrates that the impact of changing the values of the individual factors depends on what the original values were: in the specific case of Person 50, their self-control was changed from -1.207 to -0.207 while their SPI was changed from 0.0575 to -0.9425; the former change had greater impact than the latter for Person 50, but for different people this may not be the case. Indeed this was borne out when the SPI levels of Persons 0, 25, 50 and 75 were all changed, as this resulted not only in Persons 0, 25 and 75's propensities all reducing by more than when their self-control was changed, but also the propensity levels for many other people in the simulation were slightly reduced at t=260.

5.2.4.3 Test Three: Number of People

Test Three doubles the number of people input to the default model to examine whether this affects the crime propensities of the original 100 people in any way. The two versions of the people input used in this test are as follows:

- 100 people: the homogeneous people input as used in Test One;
- 200 people: Persons 1 to 100 are as above; Persons 101 to 200 are similarly homogeneous (i.e. all male, aged 21, unemployed and with no religion), with home locations between those of the first 100 people, and SPI and self-control levels allocated randomly using the same distribution as the first 100 people.

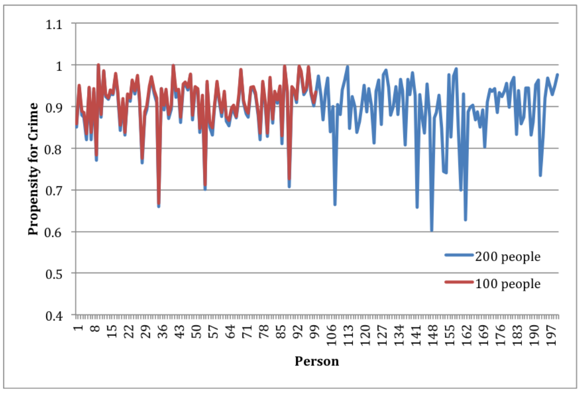


Figure 5.12: Propensities for crime after 260 time-steps for 100 and 200 people.

The resulting propensities from the two people inputs after 260 time-steps are shown in Figure 5.12. From this graph it is clear that the effect of adding people to the model on the crime propensities of the original 100 people is minimal. However, as with the previous tests, it is possible that when thresholds are introduced into the exposure and emergence transitions this result may differ. This will be examined next.

5.2.5 Changes to the Emergence transition

In Section 4.2.2 the emergence transition was defined to be a function that takes as its inputs each person's propensity for crime, their activity field, and the collective efficacy coefficient for each setting, and it outputs a value for that setting's criminogenity. Specifically, the criminogenity of setting j at time t is defined to be:

$$c_j(t) = \frac{\omega_j}{n} \left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t) > \tau_1 \\ \& \ p_i(t) > \varepsilon}} p_i(t) \right)$$

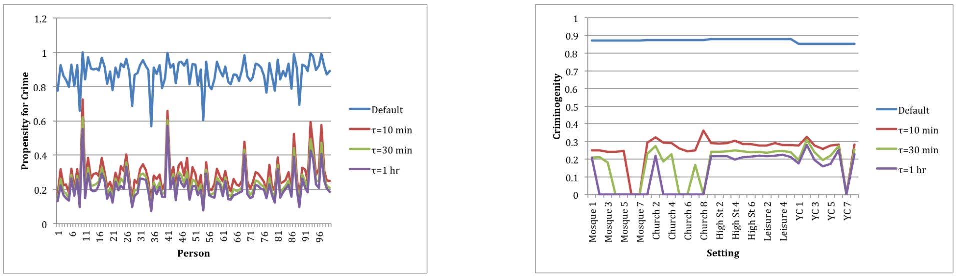
where $p_i(t)$ is the propensity of person i at time t, n is the number of people i such that $f_{ijk} > \tau_1$, and ω_j is the collective efficacy coefficient for setting j.

This section analyses the impact on the model's behaviour of changing the values of τ_1 and ε to introduce a time and propensity threshold to the emergence transition.

5.2.5.1 Changing the Time Threshold

In the default version of the model the time threshold τ_1 is set to zero. Due to the way activity fields are calculated this means that all high streets and leisure centres have the same criminogenity level, because every person in the model spends a non-zero amount of time at these locations. Similarly because all Christians, Muslims and under 20s spend a non-zero amount of time at all churches, mosques and youth clubs (respectively), these settings will also all have the same criminogenity levels (although this will vary across the different setting types). Realistically, however, one would expect that a person would need to spend a certain length of time in a particular setting before their propensity for crime has an effect on the criminogenity of the setting. It is therefore worth exploring how the model behaves when τ_1 takes a value greater than zero.

For this test three thresholds of 10 minutes, 30 minutes, and 1 hour were used to test the impact that changing the value of τ_1 has on the way the model behaves. These translate as $\tau_1 = 0.0015$, 0.0045 and 0.009 in the simulation, as τ_1 is expressed as a proportion of waking hours per week (112 hours). The impact of introducing these thresholds was measured by comparing the crime propensities of all people in the model and the criminogenity of all settings in the model after 260 time-steps with those of the default model. The resulting graphs are at Figure 5.13.



(a) Propensities **(b)** Criminogenities

Figure 5.13: Crime propensities and criminogenity levels for a subset of settings when a time threshold is introduced into the emergence transition

The key observation from Figure 5.13a is that the graphs all retain the same overall shape, although people's crime propensities are much lower even for very small non-zero values of τ_1. Additionally the peaks in the graphs are more pronounced for non-zero values of τ_1, suggesting that there is more differentiation between people's crime propensities when a time threshold for emergence is introduced. Figure 5.13b (which only shows a subset of settings for ease of display) shows that for the default version of the model there was very little difference between the criminogenity levels of settings, but for non-zero values of τ_1 differences do appear. This suggests that certain settings are more likely to become criminogenic hubs when a time threshold is introduced.

5.2.5.2 Changing the Propensity Threshold

In a similar way to changing the time threshold, it is possible to introduce a threshold for propensity. A propensity threshold in the emergence function means that an individual is required to have a certain level of propensity for crime before this has any impact on the criminogenity of the setting they are visiting.

In order to test the effects on the model's behaviour of such a change, the simulation was run for 260 time-steps with the propensity threshold ε taking a variety of different values between 0 and 1, and the resulting graphs for crime propensities and the criminogenities of settings compared. It was found that for $\varepsilon < 0.5$, changing the propensity threshold had no effect at all on either propensities or criminogenities after 260 time-steps, however for $\varepsilon \geq 0.5$ all settings have a criminogenity level of zero. This surprising result can be explained by examining what the effect of the propensity threshold is on the average criminogenity levels of all settings over the first 26 time-steps, as shown in Figure 5.14. This graph shows clearly that for the different values of ε below 0.5, while there is some differentiation between the average criminogenity levels of the settings between time-steps 4 and 20, after that all the graphs converge. Hence the propensity threshold has no effect on the final propensities at time $t = 260$. The large jump in the first time step is due to the criminogenity levels of all settings being initialised with the value of 0 while the propensity levels are initialised with the value 0.5. This makes the criminogenity levels of all settings the same for both $t = 0$ (when they are all 0) and $t = 1$, because the criminogenity levels at $t = 1$ are influenced by the propensity levels at $t = 0$, which are all above the threshold ε when $\varepsilon < 0.5$.

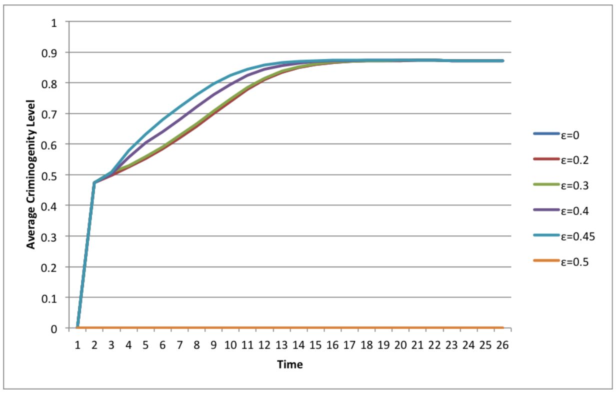


Figure 5.14: Average criminogenity level of all settings in the first 26 time-steps when different propensity thresholds are applied to the emergence transition.

This also explains the change in the behaviour of the model when ε holds values above 0.5: in this case, in the first time-step all the criminogenities of the settings remain at 0, which has the effect of reducing the propensity levels of all the people

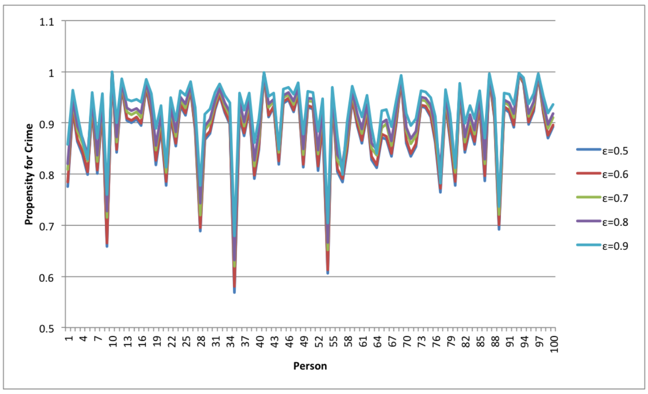


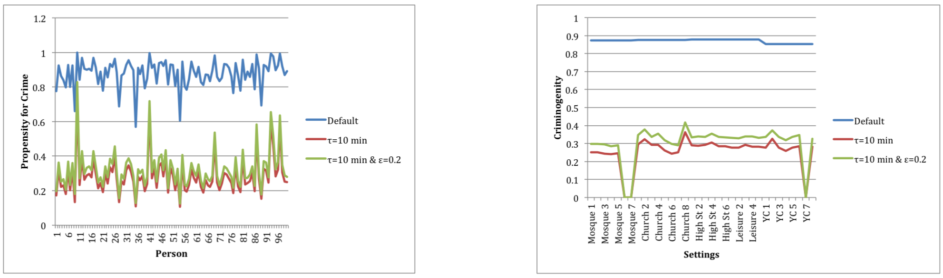
Figure 5.15: Propensities for crime after 260 time-steps when different propensity thresholds are applied to the emergence transition and the initial propensity levels are set to 1.

in the simulation below the 0.5 propensity threshold in the next time-step, and consequently the criminogenity levels never rise above 0 during the whole simulation. If the initial propensity levels are instead set higher than 0.5 we would expect the model to behave differently for $\varepsilon \geq 0.5$. Indeed, when the simulation is run with all people in the model having an initial propensity level of 1, increasing the value of ε above 0.5 was found to have small but noticeable effects on both the criminogenities and the propensities, with the possibly surprising result that at time $t = 260$ the versions of the model with the highest values of ε also had the highest propensities, as shown in Figure 5.15.

From this test we can therefore conclude that when the value of ε is increased above 0 it is essential that the initial propensities of the individuals in the model are estimated as accurately as possible, as otherwise there is a risk that the initial conditions will impair the model's ability to replicate how propensity for crime spreads.

5.2.5.3 Combined Threshold Changes

Further to changing the thresholds for τ_1 and ε separately, it is worth examining the effect of changing both simultaneously. Figure 5.16 shows the propensities and criminogenities after 260 time-steps for versions of the model using $\tau_1 = 0$ and $\varepsilon = 0$ (the default), $\tau_1 = 10$ minutes only, and $\tau_1 = 10$ minutes and $\varepsilon = 0.2$. From this it can be seen that for both propensities and criminogenities the graphs for $\tau_1 = 10$ minutes & $\varepsilon = 0.2$ are almost the same as the graphs for $\tau_1 = 10$ minutes only, but that the addition of the $\varepsilon = 0.2$ threshold slightly increases all propensities and criminogenities.



(a) Propensities **(b)** Criminogenities

Figure 5.16: Crime propensities and criminogenity levels for a subset of settings when both time and propensity thresholds are introduced into the emergence transition

A further comparison of the way the model behaves when these thresholds are applied is to examine how the mean average crime propensity changes through time over the course of 260 time-steps. This graph is shown in Figure 5.17; of particular interest is the fact that the graphs for $\tau_1 = 10$ minutes & $\varepsilon = 0.2$ and $\tau_1 = 10$ minutes only are identical for the first 26 time-steps before diverging. This is because it is only after 26 time-steps that the propensity threshold of $\varepsilon = 0.2$ starts to have an effect, for the simple reason that for the first 26 time-steps all individuals' propensities levels are above the 0.2 threshold.

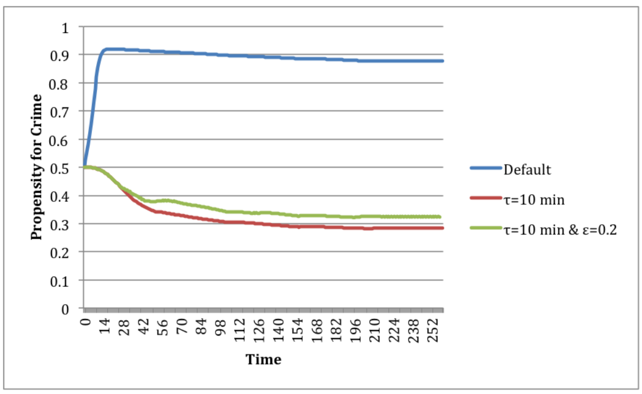


Figure 5.17: Average crime propensities over 260 time-steps when both time and propensity thresholds are introduced into the emergence transition

5.2.5.4 Integrating Threshold Changes with Settings Input Changes

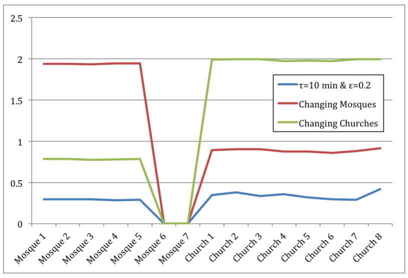
Now that the effects of changing the emergence thresholds have been examined when the model is run using the default inputs for people and settings, a further test can be conducted to understand whether these thresholds change the effects of altering the inputs.

In Section 5.2.3 the settings input was changed for the default version of the model, and when this was done it was found that increasing the size of a setting increases its prominence in a person's activity field. But what is the effect of this change on crime propensities when the thresholds of $\tau_1 = 10$ minutes and $\varepsilon = 0.2$ are in place? To answer this question a test was conducted whereby the size of two of the most criminogenic settings for the version of the model with these thresholds was doubled (the workplace "Produce World Ltd" and the religious centre "Oundle Road Church"). The direct result of this change is that these settings become more attractive to people in general, and so all people are likely to spend more time at these locations. However this may then have one of two impacts: it may cause the people visiting the setting to gain more exposure to criminogenic influences and hence increase their propensities, or it may reduce the criminogenity of these settings because more neutral people are visiting them.

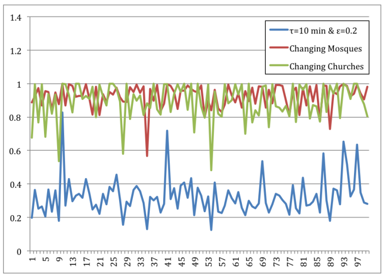
After running these model variants and comparing the criminogenity levels of the settings and the propensities of the people after 260 time-steps it was found that the second of these two scenarios is more likely: there was a small amount of variation in the criminogenities of the settings, and in particular the two settings whose sizes had been doubled had a marginally lower criminogenity level than previously. However the impact on propensity levels was minimal.

A second alteration to the settings input worth exploring is the impact of changing the collective efficacy coefficients of certain settings. We saw in Section 5.2.3 that changing the collective efficacy coefficient of a setting has minimal impact on activity fields, but we would expect it to increase a setting's criminogenity — which in turn may then also increase people's crime propensities.

A test was conducted to explore this further. In this test, the collective efficacy coefficients were doubled for all mosques, and separately for all churches, and the resulting criminogenities and propensities compared after 260 time-steps. The reason for these particular settings to be chosen is that it enables a comparison to be made between the propensity levels of Muslims and Christians in the model, which (if a significant difference is observable) would then provide a strong indication that changing the collective efficacy coefficients of settings *does* impact on the crime propensities of people who visit the settings. The results of this test are shown in Figure 5.18, where Figure 5.18a shows the resulting criminogenities of the mosques and churches, and Figure 5.18b shows the overall crime propensities.



(a) Criminogenities



(b) Propensities

Figure 5.18: Criminogenity levels of churches and mosques and crime propensities when the collective efficacy coefficients of either mosques or churches is doubled. Time and propensity thresholds for emergence are $\tau_1 = 10$ minutes & $\varepsilon = 0.2$ for all graphs.

From Figure 5.18a it can be seen that doubling the collective efficacy coefficient does increase the criminogenity level of the settings in question, as expected, while Figure 5.18b shows that the effect of this change on propensities is considerable, in that the shape of the propensities graph (which in all other tests has been reasonably stable) has been significantly altered. The impact of the tests on propensities is better understood from Figure 5.19, which shows that the average propensity levels of the Christians and the Muslims in the model has changed in line with the collective efficacy coefficient changes at their respective religious centres.

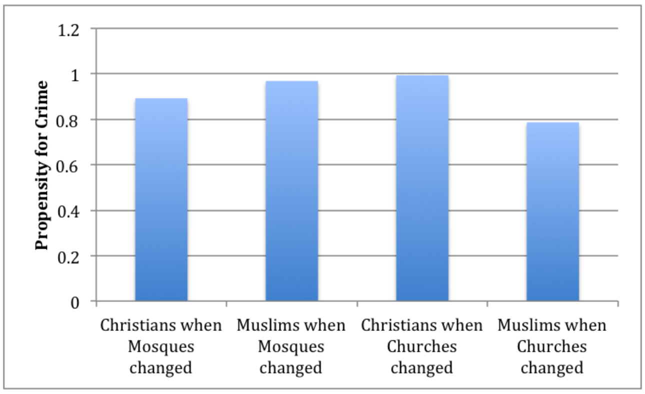


Figure 5.19: Average crime propensities for Christians and Muslims when the collective efficacy coefficients of mosques or churches is doubled.

5.2.5.5 Integrating Threshold Changes with People Input Changes

The final alteration that can be made is to the people input file in conjunction with the thresholds in the emergence transition. To investigate the effects of changing the people input file when the thresholds of $\tau_1 = 10$ minutes and $\varepsilon = 0.2$ are in place, three tests were carried out. These tests are parallels of the tests conducted in Section 5.2.4: Test One compares the impact of using a homogeneous people input as opposed to a socio-demographically diverse people input, Test Two changes the individual attributes of each person, and Test Three doubles the number of people in the model.

The simulation was run for 260 time-steps and the results compared. These are summarised as follows:

- Test One: using a homogeneous people input file increased the criminogenity levels of the settings considerably, to the extent that they exceeded the criminogenity levels reached when no thresholds were in place (with the exception of settings visited by nobody, such as workplaces and religious centres, which naturally had a criminogenity level of zero). The effect on propensity levels was similar, in that when a homogeneous input was used they became slightly higher than the propensity levels reached for the default model version with no thresholds in place; the final propensity and criminogenity levels are in fact very similar to those obtained with the homogeneous people input and no thresholds that was carried out in Section 5.2.4. This effect can be explained by the fact that when the people input is homogeneous the people divide their time between a small number of different settings (because no workplaces, religious centres or youth clubs are visited), resulting in them spending longer than the 10 minute time threshold in each setting, and therefore ensuring that they influence every setting they visit. This keeps the criminogenity levels of the setting sufficiently high to ensure that the people's propensities never dip below the 0.2 propensity threshold — resulting in those thresholds having no effect.

- Test Two: altering the geographical locations of the people created some differences in the criminogenity levels of the settings, but crime propensities remained largely unchanged. This result held both for homogeneous and socio-demographically diverse people input files. When the self-control and SPI values for a small number of individuals were changed the propensities altered in the same direction as when this test was applied to the version of the model without thresholds.

- Test Three: doubling the number of people had minimal impact on both crime propensities and criminogenity levels, for both homogeneous and socio-demographically diverse people inputs.

5.2.5.6 Summary

In conclusion, increasing the time and propensity thresholds in the emergence function has been shown to have a considerable effect on the criminogenity levels of settings overall, in that all settings have lower criminogenity levels and there is more distinction between the criminogenity levels of different settings. When implemented in conjunction with these thresholds, altering the collective efficacy coefficients also increased the criminogenity levels of the settings, while increasing the amount of time people spend at a setting (by, for example, increasing the setting's size) slightly decreased its criminogenity. Modifying the socio-demographic profiles of the people input also had a significant impact on criminogenity levels when the emergence thresholds were in place. Some of these changes also had a significant impact on crime propensities: in particular, altering the collective efficacy coefficients in conjunction with the emergence thresholds, and altering the socio-demographic profiles of the people in the model. However for other changes, such as altering the geographical locations of the people, the effects on the criminogenity levels of settings did not translate into a significant change in propensity levels, suggesting that propensities are relatively stable even when certain environmental factors are changed.

5.2.6 Changes to the Exposure transition

The default version of the model as described in Section 5.1.1 uses for the exposure function an equation taken from the negative binomial regression model derived by Meldrum et al. (2013). According to this equation, after the exposure transition, i's propensity p for crime at time t becomes:

$$p_i(t) = 1 - \left(\frac{1}{1 + 0.1228e^{-0.23+0.25x_1(t)-0.13x_2+0.15x_1(t)x_2+0.69x_3(t)}} \right)^{8.14}$$

where x_1 is i's susceptibility to peer influence, x_2 is i's self-control (static over time), and x_3 is the amount of criminogenic exposure that person i has had (all converted to z-scores).

This section considers the effect of making changes to the exposure transition in two areas. The first is changing the way that criminogenic exposure (x_3) is defined, in order to incorporate a time threshold and to extend the amount of influence that each criminogenic setting has on a person to more than one time-step. The second change is more fundamental, and involves changing the entire function from the negative binomial equation to the alternative equation derived from the work of Gino et al. (2011) and Wikström (2009a) which was discussed in Section 4.1.4.1.

5.2.6.1 Changing the Criminogenic Exposure

In the default version of the model, criminogenic exposure (Exp) is taken to be the mean average of the criminogenity of each setting visited by person i that time-step. In other words:

$$Exp_i(t) = \frac{1}{n}\left(\sum_{\substack{\forall j \text{ s.t.} \\ f_{ijk}(t)>0}} c_j(t)\right)$$

where n is the number of settings j such that $f_{ijk}(t) > 0$.

In order to understand the impact of changing the way criminogenic exposure is defined on the model's behaviour, three tests will be undertaken. These three tests are detailed below.

Test One: The first test introduces a simple time threshold τ_2, similar to that used in the emergence transition, so that the criminogenity of setting j only counts towards the exposure gained by i if $f_{ijk}(t) > \tau_2$. So:

$$Exp_i(t) = \frac{1}{n}\left(\sum_{\substack{\forall j \text{ s.t.} \\ f_{ijk}(t)>\tau_2}} c_j(t)\right)$$

This value is then converted to a z-score using the same values for the mean and variance as in the default model.

Test Two: The second test modifies the criminogenic exposure definition so that instead of it simply being the average criminogenity of all settings visited, the criminogenities are weighted according to how long a person spends in each setting. Although this is a theoretical test rather than one based on empirical research, common-sense logic behind this definition is that a person would be more influenced by the criminogenity of settings where they spend more time than settings where they spend very little time.

For Test Two criminogenic exposure is defined to be:

$$Exp_i(t) = \sum_{\forall j} f_{ijk}(t).c_j(t)$$

This value is then converted to a z-score using the same values for the mean and variance as in the default model.[1]

Test Three: The third test incorporates an exponential decay in the criminogenic exposure definition. The logic behind this is that the criminogenic influence of a setting on a person may last longer than just one time-step (i.e. one week), but that any influence would be expected to decrease with time if the person does not continue to visit the setting.

For Test Three criminogenic exposure is defined to be:

$$Exp_i(t) = \lambda Exp_i(t) + (1-\lambda)Exp_i(t-1)$$

which, when $\lambda = \frac{1}{2}$, is the same definition as for the default version of the model but averaged with that of the previous time-step. This value is then converted to a z-score using the same values for the mean and variance as in the default model.

5.2.6.2 Results

Test One: Incorporating a time threshold into the exposure function has little impact on either crime propensities or the criminogenity levels of settings when applied to the default version of the model. However, when applied to a version of the model that has low thresholds in the emergence function ($\tau_1 = 10$ min and $\varepsilon = 0.2$), incorporating a 10 minute time threshold in the exposure function has the effect of reversing the effects of the emergence function thresholds, so the resulting crime propensities and criminogenities return to the higher level that the default version of the model produces. However in this case increasing τ_2 further has very little

[1]The true values for the mean and variance of Test Two's definition of $Exp_i(t)$ cannot be calculated analytically. The sample mean and variance for Test Two's $Exp_i(t)$, calculated using randomly generated values for x_1, x_2 and x_3, were found to be similar to those for the default model.

impact on either criminogenities or propensities.

Using a higher time threshold in the emergence function ($\tau_1 = 1$ hour) creates a more interesting pattern. In this case, having no time threshold in the exposure function ($\tau_2 = 0$) results in relatively low propensity and criminogenity levels. Increasing τ_2 then leads to successively higher propensity and criminogenity levels, until at $\tau_2 = 1$ hour the pattern of the graphs is very similar to that of the default model. Graphs showing these effects for crime propensities is shown in Figure 5.20.

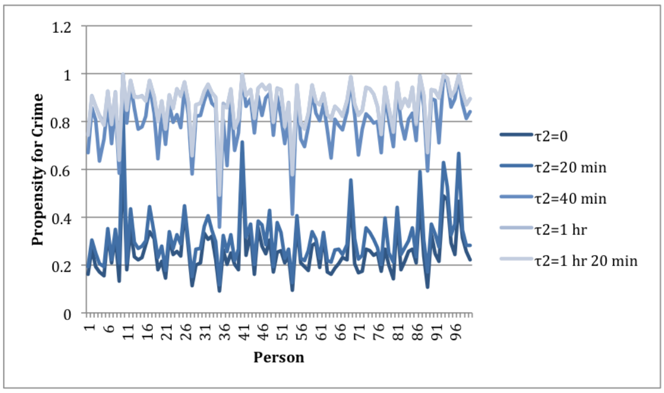


Figure 5.20: Effects of introducing a time threshold τ_2 into the definition of criminogenic exposure. These graphs show the value of each person's propensity for crime after 260 time-steps for a version of the model that uses $\tau_1 = 1$ hour and $\varepsilon = 0.2$ in the emergence function.

Test Two: Comparing Test Two's version of the model with the default version suggests that changing the criminogenic exposure function in this way has very little impact on either crime propensities or criminogenity levels. However when this change is applied to the version of the model that has low thresholds in the emergence function ($\tau_1 = 10$ min and $\varepsilon = 0.2$), Test Two's criminogenic exposure function reverses the effects of the thresholds and produces a very similar pattern of outputs to those of the default model. This could be interpreted as the change in how criminogenic exposure is defined removing the effects of the emergence thresholds. An alternative interpretation is that while only a low threshold in the emergence function is required to affect crime propensities and criminogenities when the default definition of criminogenic exposure is used, Test Two's version of criminogenic exposure requires higher thresholds in the emergence function before these thresholds have any impact. A further test to explore the effects on crime propensity of increasing the emergence threshold τ_1 when Test Two's version of the criminogenic exposure function is used yields the graphs shown in Figure 5.21. These graphs show clearly that when the threshold τ_1 is increased, people's crime propensities reduce gradually.

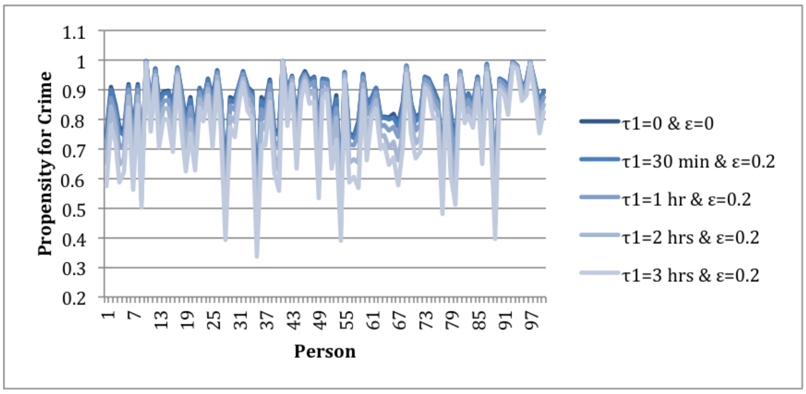


Figure 5.21: The value of each person's propensity for crime after 260 time-steps for a version of the model that uses weighted criminogenities in the criminogenic exposure function, and varying values for the emergence threshold τ_1. The emergence propensity threshold remains $\varepsilon = 0.2$ throughout.

Test Three: Extending the length of time that each setting has an influence on the people in the model via an exponential decay has very little impact on the outputs of the model at time t=260. When the average crime propensities and criminogenities of settings are analysed over time, the version using the exponential decay takes longer to reach its final values than the default version, but these final values remain the same. This result holds for versions of the model with and without thresholds.

5.2.6.3 Changing the Entire Exposure Function

As the previous tests have shown, there is a considerable amount of stability in the crime propensities generated by the negative binomial regression model used in the default exposure function. However, as was discussed in Section 4.1.4.1, this equation is not the only credible means of linking the variables of morality, self-control, criminogenic exposure and propensity. As using an alternative function may produce very different results, it is worthwhile exploring the impact of replacing the negative binomial function with another theoretically credible function, and testing how the model behaves with this new function. We shall therefore run the model using the alternative equation in the exposure transition that was first derived in Section 4.1.4.1; that is, the equation derived from the work of Wikström (2009a) and Gino et al. (2011), from which an equation was constructed putting person i's morality at time t as

$$m_i(t) = x_1 + \theta x_3 e^{-\gamma x_2}$$

and their propensity for crime as

$$p_i(t) = m_i(t) - x_2$$

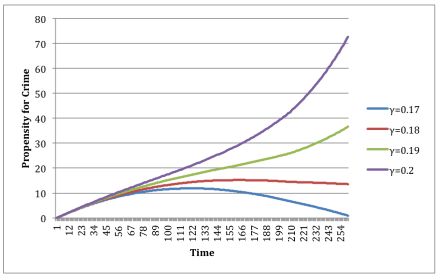
where x_1 (susceptibility to peer influence) and x_2 (self-control) are independent random variables distributed $N(0,1)$, x_3 is the z-score derived from the criminogenic exposure function as defined as in the default version of the model, and θ and γ are model parameters.

5.2.6.4 Model Behaviour

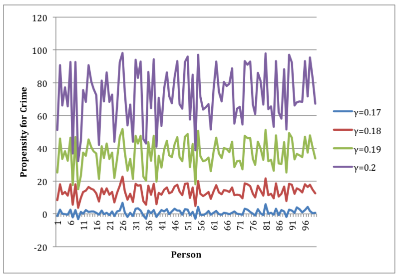
Using this new exposure function, the simulation was re-run over 260 time-steps and the outputs compared with the default version of the model. The first observation is that, while for the default version of the model crime propensity is a probability and is therefore bounded in the interval [0, 1], for the new version propensity is unbounded and could hold any real value. To accommodate this the propensity threshold ε in the emergence function has been removed entirely in order to allow the propensity levels to float freely while this new version of the model is being tested.

Before conducting the same series of tests as were done on the model that used the negative binomial exposure function, the impact of changing new model parameters θ and γ was explored. In particular, the average propensity levels over time and the propensity levels of all people in the model at time $t = 260$ were compared for different values of θ and γ, and it was observed that for some values of θ and γ the average crime propensity converges over time, while for other values it diverges.

One example of the variety of patterns produced is shown in Figure 5.22a. These graphs show that when $\theta = 1$, γ has to be less than approximately 0.19 to stop the average propensity level spiralling towards infinity. The pattern of propensities across all people at time $t = 260$ similarly shows that for higher values of γ the propensities themselves are higher and also have a larger variance.



(a) Average propensities over time



(b) Propensities at $t = 260$

Figure 5.22: Propensities for crime over time and at $t = 260$ using the new exposure function with $\theta = 1$ and γ taking a number of different values.

In order to understand why the simulation converges in some circumstances but not in others, the equations explaining the exposure and emergence transitions need to be rewritten to enable the variable p to be defined as a function of time. This requires a number of simplifications to be made, because the precise circumstances under which the exposure or emergence functions will be called depend on the activity fields. However, if one assumes that all people visit all settings (thereby eliminating the influence of the activity fields), that susceptibility to peer influence is constant, and that all people in the model have the same x_1 and x_2 values, a person's propensity for crime as a function of t can be written

$$\begin{aligned} p(t) &= x_1 - x_2 + \theta e^{-\gamma x_2} p(t-1) \\ &= (x_1 - x_2) \sum_{k=0}^{t-1} \left(\theta e^{-\gamma x_2}\right)^k \end{aligned}$$

This is a geometric series. It follows that as $t \to \infty$, the series will converge if and only if $|\theta e^{-\gamma x_2}| < 1$. But x_2 is a random variable distributed $N(0,1)$ and can take any real value, meaning that for different people inputs to the model, different values of θ and γ will produce different results. Further, the assumptions made that have allowed the influence of activity fields to be eliminated are not realistic ones; in the real model if one person's x_2 value would allow propensity to converge over time while someone else's would cause it to diverge, in an actual simulation the divergence property would spread throughout the model. We can conclude that person i's propensity will converge only if $|\theta e^{-\gamma x_2}| < 1$ holds for every person in the model.

Problems over convergence aside, the patterns produced by each of the graphs at time $t = 260$ are similar in shape to each other and indeed they also mirror the pattern produced by the negative binomial version of the model. This is better illustrated in Figure 5.23, which compares the shape of the propensity graphs at t=260 produced by the default negative binomial model with those produced by the new model using two different θ and γ combinations. They are not identical, but they do all agree on which people in the model have the higher and lower propensity levels.

However, it is noteworthy that the equivalent graphs showing the criminogenities of settings (shown in Figure 5.24), tell a very different story. These graphs show the criminogenity levels of public settings (i.e. non-residential settings — the private residences have criminogenity levels very similar to the propensity levels of their inhabitants). From these graphs it can be seen that the settings that are the most criminogenic in one version of the model are not the settings that are most criminogenic in other versions of the model — and yet the three models give similar relative propensity levels for all the individuals. This suggests that the emergence of criminogenic settings does not have a large influence on the propensity levels of individuals. However it should be recalled that all versions of the model used in this comparison have no thresholds in the emergence function, and that the collective efficacy for all settings is 1; when these values are changed, criminogenic settings would be expected to have a far greater influence on people's propensities.

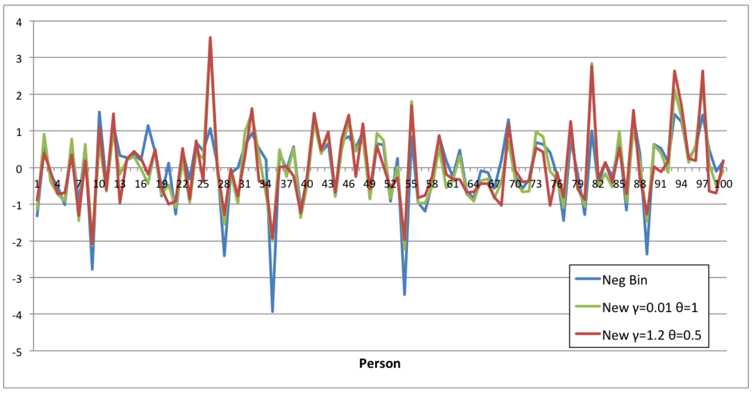


Figure 5.23: The value of each person's propensity for crime after 260 time-steps for the default negative binomial model and the new model using different values for θ and γ. For ease of comparison propensities have been transformed to ensure a mean of 0 and standard deviation of 1 for all model versions.

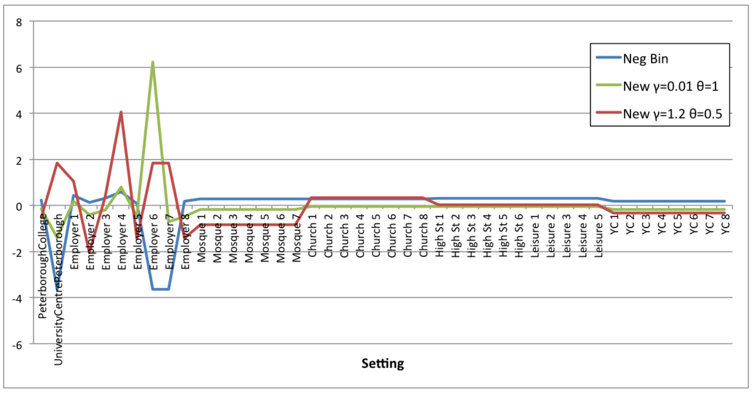


Figure 5.24: The criminogenity levels of the public settings after 260 time-steps for the default negative binomial model and the new model using different values for θ and γ, transformed the ensure a mean of 0 and standard deviation of 1. Schools have been excluded because at $t = 260$ all individuals in the model are above school-age.

5.2.6.5 Testing the Alternative Model

Once the basic behaviour of the new version of the model was understood for different θ and γ values, the same tests were applied to this model as were carried out with the negative binomial version. Specifically, tests were undertaken to explore the effects of altering the people input, settings input, the emergence function and the criminogenic exposure function. These tests were applied to a version of the model that has $\theta = 0.5$ and $\gamma = 0.5$, which is a version for which the propensity levels all converge.

The tests that involved changing the composition of the people input to the model saw the new version of the model behave in the same way as the negative binomial version in almost all cases. These results are summarised as follows:

- Using a homogeneous people input file has very little impact on crime propensities at $t = 260$.
- Altering the geographical locations of the people input in the model also has very little impact on crime propensities.
- Altering the self-control and susceptibility to peer influence of a small number of people in the model altered the propensities of the people concerned, although this had virtually no impact on any other people in the model. The effect of increasing self-control by 1 or decreasing SPI by 1 was almost identical, and in both cases resulted in a reduction in the specific persons' propensities. (This differs from the result for the negative binomial version of the model, where the impact of increasing self-control for Person 25 was to increase his propensity, and the impact of changing self-control and SPI produced different results for all people.)
- When the number of people in the model is doubled, the crime propensities for the original 100 people remain almost identical.

However, differences were observed in how the new version of the model behaves when compared with the negative binomial version when time thresholds were applied to the emergence transition. When thresholds were applied to the negative binomial version these did alter the crime propensities to some degree, but for the new version of the model almost no change was perceptible. Changing the collective efficacy coefficients of the mosques and churches when a time threshold was in place did have the expected effect on the propensity levels of Muslims and Christians, but all other propensities were almost unchanged.

Similarly, when changes were applied to the way criminogenic exposure was defined, the new version of the model exhibited almost no change to the ultimate levels of crime propensities. This stability in crime propensities held for all changes made to the criminogenic exposure function (i.e. introducing a time threshold, weighting the criminogenities according to time spent in settings, and incorporating exponential decay).

In summary, changing the function in the exposure transition from a negative binomial distribution to an alternative (but theoretically credible) function has demonstrated that certain features of the model are very stable. In particular, altering the characteristics of the people in the model has the expected impact for both model versions in almost all cases, and similarly when the collective efficacy coefficients for certain settings are changed. The basic pattern of crime propensities also remains consistent when changes such as the introduction of time thresholds are incorporated into the emergence or exposure transitions, although the precise impact of these thresholds does vary. However, from these tests it can be concluded that the basic behaviour of the computer simulation is reasonably consistent overall when an alternative theoretically credible function is used in the exposure transition.

5.2.7 Model Validation

Section 3.2.6 listed five stylised facts concerning criminality development that the model should ideally be replicating. These stylised facts were as follows:

1. The agents in the model should be heterogeneous with regard to criminal propensity;
2. The distribution of propensities across the population should be positively skewed;
3. An individual's propensity for crime can increase or decrease over time;
4. A steady state for the system overall should not be reached;
5. Average propensity for crime reduces with age.

We shall now establish whether the model (using either the negative binomial function or the alternative function) satisfies these criteria.

1. Heterogeneity of agents

From the graphs at Figures 5.2, 5.22b and 5.23 it is evident that the propensities of the agents in the model are different for both versions of the model.

2. Distribution of propensities for crime

Histograms showing the distributions of crime propensities for the negative binomial version of the model with $\tau_1 = 10$ minutes and $\varepsilon = 0.2$ and the alternative version using two different values for θ and γ are displayed in Figure 5.25 (to facilitate comparison the propensities for the three sets of data have been standardised so they have mean 0 and variance 1). From these it can be seen that the distributions for all three versions of the model are similar, and that there is a slight positive skew. We can therefore conclude that the model does reproduce this stylised fact.

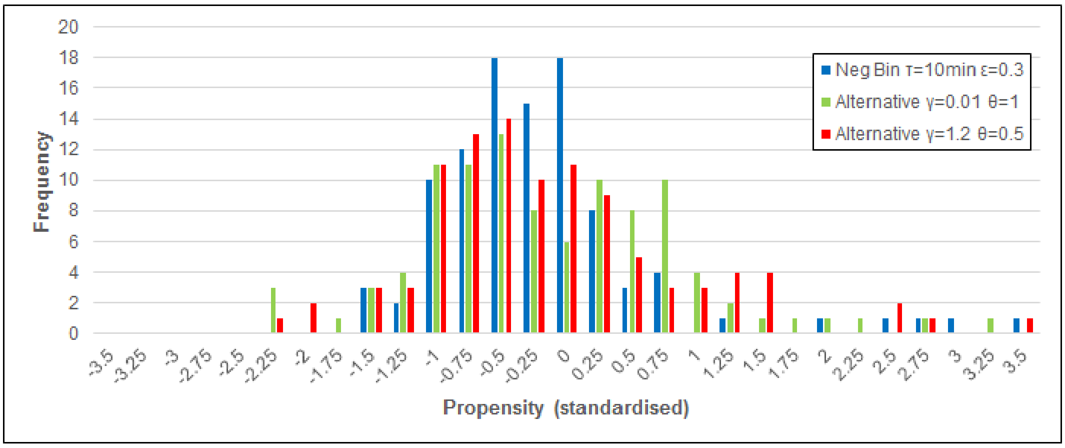
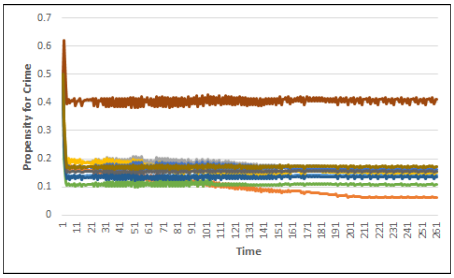


Figure 5.25: Histogram showing the distribution of propensities for crime for the negative binomial model with $\tau_1 = 10$ minutes and $\varepsilon = 0.2$ and the alternative version with different θ and γ values at time $t = 260$ (standardised)

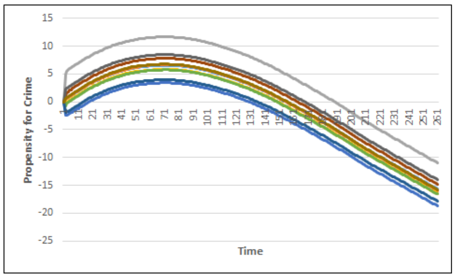
3. Change in propensity for crime

Figure 5.26 show the propensity for crime of a random 10 individuals in the model throughout the 260 timesteps of the simulation, for three different versions of the criminality development model (as before, the three versions of the model used for the test are the negative binomial version with $\tau_1 = 10$ minutes and $\varepsilon = 0.2$, the alternative version with $\theta = 1$ and $\gamma = 0.01$, and the alternative version with $\theta = 0.5$ and $\gamma = 1.2$).

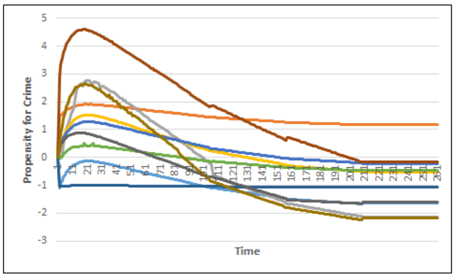
One striking thing about these three graphs is how different they are, but a trait that all three of them share is that propensity for crime does indeed both increase and decrease at different stages in the simulation. Therefore this stylised fact is fully addressed by the model.



(a) Negative Binomial with $\tau_1 = 10$ minutes and $\varepsilon = 0.2$



(b) Alternative with $\theta = 1$ and $\gamma = 0.01$



(c) Alternative with $\theta = 0.5$ and $\gamma = 1.2$

Figure 5.26: Propensity for crime of 10 individuals in the model over 260 time-steps

4. Lack of steady state

The graphs at Figure 5.26 also provide evidence as to whether the simulation outputs reflect the fourth stylised fact: that a steady state should not be reached because propensity for crime can always change. The three graphs provide three very different answers to whether this stylised fact is met. Figure 5.26a, from the negative binomial version of the distribution, suggests that there is stability in the model towards the end of the simulation, but that individual fluctuations in propensity still occur. Thus this graph shows that this version of the model does reflect this stylised fact.

The second graph, Figure 5.26b shows that no steady state has been reached in this model and that propensity is constantly changing; however, this is a version of the model that does not converge and is therefore already to be regarded as unrealistic, despite it technically addressing this stylised fact.

The third graph, Figure 5.26c, shows the outcome of a simulation that does reach a steady state. This simulation therefore does not address this stylised fact. However it should be recalled that the model as it is currently configured does not allow for changes in the environment, or for people to enter or leave the model. If these additional features were incorporated the propensities may continue to change throughout for all model versions.

In summary, this stylised fact can be addressed by the model in theory, but whether it does — and whether the way it does is realistic — are highly dependent on the function chosen in the exposure transition.

5. Average propensity for crime decreasing with age

A graph showing the average propensity for crime at the end of the simulation for people of different ages for three versions of the model is shown in Figure 5.27. As before, the three versions of the model used for the test are the negative binomial version with $\tau_1 = 10$ minutes and $\varepsilon = 0.2$, and the alternative version with two different values for θ and γ (all standardised). These graphs show that there is not a clear correlation between age and criminal propensity; indeed for the three sets of data the correlation coefficients against age are 0.157 (negative binomial version), 0.448 (alternative version with $\gamma = 0.01$ and $\theta = 1$), and 0.287 (alternative version with $\gamma = 1.2$ and $\theta = 0.5$) — all positive values, but in some cases only very weakly positive. However as there are only 100 people in the simulation each age bracket contains only 5 or 6 people; it is therefore unsurprising that these results are quite noisy. It can be concluded that this stylised fact is partially met by the simulation.

To summarise, of the five stylised facts that the model is required to address, all versions of the model fully satisfy the first three. The fourth stylised fact is reflected in the negative binomial version of the model, but the alternative version either does not reproduce this stylised fact or else it does so in an unrealistic way. The fifth stylised fact is partially addressed by the model. In conclusion, some versions of

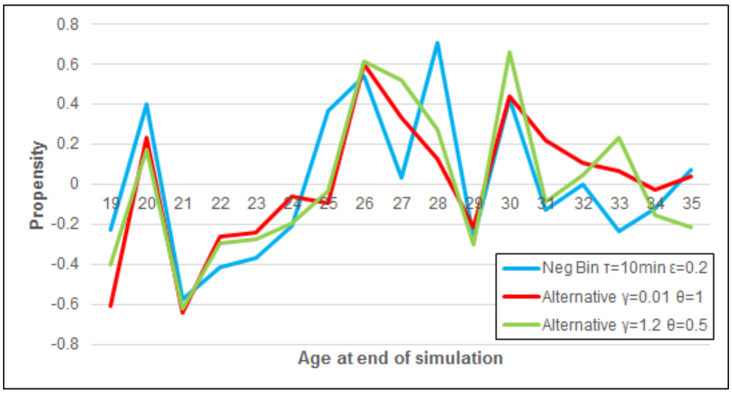


Figure 5.27: Graphs showing the average propensity for crime against age at the end of the simulation for the negative binomial model with $\tau_1 = 10$ minutes and $\varepsilon = 0.2$ and the alternative version with different θ and γ values (standardised)

the simulation model do fully reflect the traits of the phenomenon that they seek to explain, but care must be taken when defining the parameters in the model — especially with regard to the function chosen in the exposure transition — to maximise its validity.

5.3 Summary

This chapter began with a description of each of the functions and parameters that make up the default version of the model, followed by examining how the default model behaved in terms of the change in each person's propensity for crime over time, the variation in crime propensities across all the people in the model, and the variation in the criminogenities of the settings. This section was followed by an exploration of how the model behaved differently when compared with this default version when alterations were made to each part of the model.

Changes were made to the way that activity fields were generated, the inputs to the model (both people and settings), and the emergence and exposure transitions. However not all possible changes that could have been made to the model have been explored in this chapter. For instance, further changes could have been made to the way activity fields are generated through changing the similarity function $S_{ij}(t)$. Changes could also have been made to the people input during the model (for instance to allow for people to change occupation or for new people to come into the model). But, although not completely comprehensive, the alterations that were explored in this chapter were sufficient to enable a complete understanding of how the different parts of the model interact with each other, and in particular under what circumstances the model is stable and when it is more volatile.

Although some parts of the model were derived from empirical data, other parts of the model were far more theoretical. Further empirical research, targeting specific areas such as what attracts a person to one setting over another, would be required to ensure that the criminality development model is correctly parameterised. However even at this early (and highly theoretical) stage of model development it is clear that the simulation is capable of producing results that are sufficiently consistent that a model of this type could conceivably be of use to practitioners wishing to understand which individual, social or environmental attributes make people most at risk of developing a high propensity for crime.

In the next chapter this model will be adapted further in order to convert it into a model that describes the process by which a person develops the propensity to commit acts of terrorism — that is, radicalisation.

Chapter 6

A Model for Radicalisation

The model constructed and tested over the past two chapters has allowed us to better understand which factors are most important in the criminal propensity development process, and how stable the model is when changes are made to its inputs and parameters. However the research question concerns not only the criminality development process, but the difference between it and the radicalisation process. For this we need models describing both processes. How then can the computer simulation be modified in order to make it applicable to radicalisation instead of general crime?

Three theoretical differences between criminal propensity development and radicalisation were suggested in Chapter 2: these were in the severity of the crimes involved, the level of morality required for a person to have the propensity to act, and the rarity of radicalising settings. Section 4.3 then briefly considered how these could be incorporated in the model, by interpreting the model outputs in a different way, and making alterations to the emergence transition that make radicalising settings less likely to appear. In the first section of this chapter these changes will be implemented and the subsequent behaviour of the model analysed, in order to determine whether the changes produce credible results. A number of approaches to finding suitable values for the model's parameters in the absence of empirical data are then pursued. Once such parameters are established, the chapter goes on to use this model to explore how radicalisation could take off in an unstable, lawless environment. The radicalisation model is then validated, and then used in combination with the previous chapter's criminality development model to provide an initial answer to the research question.

The chapter ends with a brief exploration of how the radicalisation model could be extended to include virtual settings.

6.1 Modifying the Criminal Propensity Development Model

Chapter 5 examined the behaviour of many different versions of the criminal propensity development model. Some versions were very similar to each other, varying only in the size of a threshold, while others were very different, such as when the negative binomial equation in the exposure function was replaced with an alternative function. So which version should form the basis of the radicalisation model?

From a theoretical perspective, any version of the model could be used as they are all consistent with the theory and the IVEE framework. However the versions of the model that use the alternative exposure function have a number of disadvantages. The function used was devised purely from theory in order to provide an example of what changes might be realistic, and is not based on any empirical data. Because of this it is not possible to interpret what the final propensity levels actually represent, and therefore what it would mean for somebody to count as a "radical". Conversely, the negative binomial equation in the default version of the model was taken directly from an empirical study and allows us to interpret the propensity values as representing probabilities that people will commit crime over the course of the next year. This provides a far clearer basis on which to build, and so the negative binomial version of the model will be used as the starting point for the radicalisation model.

The first change necessary to make this model applicable to radicalisation is to increase the severity of the crimes for which an individual may have the propensity. It was suggested in Section 4.3 that this could be done by putting in place a high threshold whereby anyone with a propensity over this threshold would be considered a radical. However, a high threshold — say a threshold of 0.99 — simply means that there is a probability of 0.99 that the person will commit *any* crime, and does not say anything about their likelihood of committing *severe* crimes. In order to focus the model on severe crimes, changes need to be made to the parameters within the negative binomial function. To determine what these changes should be, we need to return to the way the negative binomial function was derived.

As described in Section 4.1.4, a random variable Y is negatively binomially distributed if the probability that Y is equal to y is:

$$P(Y=y) = \frac{\Gamma(y+\frac{1}{\alpha})}{\Gamma(y+1)\Gamma(\frac{1}{\alpha})}\left(\frac{1}{1+\alpha\mu}\right)^{\frac{1}{\alpha}}\left(\frac{\alpha\mu}{1+\alpha\mu}\right)^{y}$$

where the mean of the distribution is μ, and α is the "heterogeneity parameter" (Hilbe, 2011). In a negative binomial regression these parameters are estimated from a set of data; for instance μ is estimated by

$$\ln\mu = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$$

for n independent variables. In the criminality propensity development model these parameters were taken from the work done by Meldrum et al. (2013), which gave $\alpha = 0.1228$ and

$$\ln\mu = -0.23 + 0.25x_1 - 0.13x_2 + 0.15x_1x_2 + 0.69x_3$$

where x_1 is susceptibility to peer influence, x_2 is self-control, and x_3 is peer delinquency. Propensity is then calculated as $p = P(Y>0) = 1 - P(Y=0)$. As all the x_i values are z-scores, this gives an expected value for an average person's propensity of

$$E(p) = 1 - \left(\frac{1}{1+0.1228e^{-0.23}}\right)^{8.14} = 0.5314$$

This can be interpreted as the probability that an average person with average exposure does commit a crime at some point over a 12 month period.

As no empirical studies have been carried out replicating the results produced by Meldrum et al. (2013) for terrorism, there is no data on which to draw to adapt this equation into one more applicable to radicalisation. However, some common-sense logical changes can be made. Firstly, as we are defining a radicalised person as someone with the propensity to commit severe crimes that are very rare in UK society, the expected value for an average person's propensity for such crimes needs to be far, far lower than 0.531. Moffitt et al. (1989) observed that the rate of conviction for a violent offence in young adult males is between 3% and 6%; when spread across the whole population this number becomes lower still, and then even lower again if one considers the probability that the violent offence is committed in a particular 12 month period. A more realistic value then would perhaps be 0.001 for such rare events. Assuming the value for the heterogeneity parameter α remains unchanged, this would suggest $\beta_0 = -6.91$, as

$$E(p) = 1 - \left(\frac{1}{1 + 0.1228e^{-6.91}}\right)^{8.14} = 0.001$$

Secondly, the role of morality is more important in a person's propensity for terrorist actions than the role of self-control, because terrorism requires more premeditation. This is already incorporated into the negative binomial function in the criminality development model to a certain extent, because $\beta_2 = -0.13$ is smaller in magnitude than $\beta_1 = 0.25$. However for the radicalisation model the influence of self-control should be reduced further: an initial attempt at suitable values could be to have $\beta_2 = -0.10$ while keeping $\beta_1 = 0.25$. The remaining parameters will remain unchanged, as without data on which to base the model, no other changes can be justified.[1] This gives an equation for the exposure transition of

$$p_i(t) = 1 - \left(\frac{1}{1 + 0.1228e^{-6.91+0.25x_1(t)-0.1x_2+0.15x_1(t)x_2+0.69x_3(t)}} \right)^{8.14}$$

where $p_i(t)$ is the propensity of person i at time t. One observation that can immediately be made about this equation is that the magnitude of $\beta_0 = -6.91$ is considerably larger than the other β_i values, meaning that x_1, x_2 and x_3 would need to be large for them to have much effect at increasing the propensity of i significantly above 0.001. However while the equation may look unusual from a mathematical perspective, this is precisely the effect that we are trying to achieve, as we are seeking to replicate the rarity of radicalisation in society.

Aside from the negative binomial regression, the emergence function needs to be altered in order to make the emergence of radicalising settings a rarer occurrence than the emergence of criminogenic settings. As with the changes made to the emergence function in Chapter 5, there are three changes that could be made: setting a time threshold τ_1, setting a propensity threshold ε, and changing the impact of the collective efficacy factor.

Taking this last suggestion first, the literature for both development processes consider collective efficacy to be important, so it should certainly remain as part of the emergence function. In the criminality development model the collective efficacy coefficient is multiplied by the average propensity of people visiting a setting in the emergence function, so that a setting with twice the collective efficacy of another becomes twice as criminogenic (with all other factors being equal). This works in the criminality development model because propensities for crime are approximately normally distributed and having a relatively high propensity is not a rare occurrence, so it is primarily the collective efficacy coefficient that determines which settings are the more criminogenic. But in the radicalisation model it will be unusual for anyone to have a high enough propensity to cause a radicalising setting

[1] The mean and sample variance used to transform criminogenic exposure into a z-score have also been changed to take into account the new values of β_i.

to emerge at all. It should therefore be the presence of radicalised people in the setting, not the collective efficacy coefficient, that makes a setting radicalising. The impact of a high collective efficacy coefficient on the extent to which the setting emerges as a radicalising setting should therefore be reduced; it should still have an effect, but that effect should be less than it is for the criminality development model.

How about the impact of a low collective efficacy coefficient? If we take the default collective efficacy coefficient of a setting to be one, settings with a value of $\omega_j < 1$ will be settings with high levels of informal social control and high levels of social cohesion. These settings are less likely to become criminogenic, but if a radicalised person were present we would still expect them to have an influence on others at the setting, although that influence might well be lower than in other settings. An example might be a highly radicalised pupil at a school: the school itself might have high levels of collective efficacy making the radicalised pupil unlikely to actively recruit fellow pupils while at school, but they could still build relationships with their fellow pupils with the intent of recruiting them in a different setting.

In order to reduce the impact of collective efficacy in the radicalisation model's emergence function we need to replace multiplying the average propensity of the people visiting the setting by ω_j with multiplying it by some function $f(\omega_j)$. That function should keep $f(1) = 1$, but for $\omega_j > 1$ we need $f(\omega_j) < \omega_j$ and for $\omega_j < 1$ we need $f(\omega_j) > \omega_j$. A simple linear function of $f(\omega_j) = a\omega_j + b$ for $a \in (0,1)$ and $b = 1 - a$ would work, as would the non-linear option of $f(\omega_j) = \omega_j^{\phi}$ for $\phi \in (0,1)$. As the collective efficacy coefficients used in the model are not based on actual data, it is not possible at this stage to know which function would be more suitable; for this first version of the radicalisation model the function $f(\omega_j) = \omega_j^{\phi}$ will be used.

An additional way to integrate the role of collective efficacy in the model is to make it part of the propensity threshold in the emergence function, so that a lower propensity is required to make a radicalising setting emerge if it has a higher collective efficacy coefficient (recall that the scales are reversed, so a setting with low collective efficacy has a high collective efficacy coefficient). The "standard" propensity threshold that would apply to settings with a collective efficacy coefficient of 1 need not be very high, as propensity in the radicalisation model refers to very severe crimes only. For instance if a person has only a 10% chance of committing a very severe crime in the next 12 months, that may make them sufficiently radicalised to have a radicalising influence on others. For this first attempt at parameterising the radicalisation model we shall therefore set $\varepsilon = 0.1$, and make the propensity threshold for a setting j equal to ε/ω_j.

As for the time threshold, case studies including those described by Sageman (2004) and Pantucci (2010) have described the locations of key radicalising settings for a number of individuals' radicalisation experiences. For instance, Abu Qatada al-Filistini was active at a youth club in north London which became a rallying point for London-based Algerian Islamists, while Abu Hamza al-Masri — the "hook-handed sheikh" — drew "angry young men" around him at the Finsbury Park mosque (Pantucci, 2010). These locations are visited by people for a reasonable length of time — they do not become radicalising over the course of just 10 minutes of attendance per week. However, a radicalised person does not need to spend the majority of their waking hours there either to be highly influential. With this in mind, we shall set the time threshold τ_1 to be 1 hour per week.

Finally, a threshold needs to be set which defines someone as being "radicalised" or "not radicalised" based on whether their propensity is higher or lower. This is very subjective, as we are dealing with probabilities rather than certainties. However the heterogeneity parameter α in the negative binomial distribution acts as a useful guide, as $\frac{1}{\alpha}$ is the number of "failures" expected before one "success", where in this case a "success" means committing a severe crime. This suggests that a person has (for our value of α) approximately $\frac{1}{\alpha} = \frac{1}{0.1228} = 8.14$ opportunities to carry out a severe crime where they do not do so, before they finally do. A propensity of $\alpha = 0.1228$ therefore seems a good starting point to define what it means to be "radicalised" in the absence of empirical data.

Our first attempt at a radicalisation model will therefore use the same inputs and activity field generation as the default criminality development model, but with the following functions used for the transitions:

Exposure: After the exposure transition the propensity p of person i to commit an act of terrorism is:

$$p_i(t) = 1 - \left(\frac{1}{1 + 0.1228e^{-6.91+0.25x_1-0.1x_2+0.15x_1x_2+0.69x_3}} \right)^{8.14}$$

Emergence: After the emergence transition the radicalisation level r of setting j is:

$$r_j(t) = \frac{\omega_j^{\phi}}{n} \left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t) > \tau_1 \\ \& \; p_i(t) > \varepsilon/\omega_j}} p_i(t) \right)$$

for $\phi < 1$, $\tau_1 = 1$ hour and $\varepsilon = 0.1$.

It is recognised that these parameter values are not derived from empirical data, and that the radicalisation model is a theoretical one that may not replicate reality to a great degree. However as the decisions on which parameters to change and in what way they should be changed are based on logical conclusions drawn from analysing the literature it is hoped that this model will be more reminiscent of radicalisation than the version that describes the development of criminal propensity. All that remains therefore is to run the model and examine how it behaves, and from this we can draw conclusions as to its realism.

6.1.1 Radicalisation Model Behaviour

When the simulation is run for 260 time-steps using the default people and settings, the number of radicals is zero. Increasing the number of people in the model up to 500 still produces zero radicals, and indeed the highest propensity reached by anyone in the model over the whole simulation is 0.0075, which is significantly lower than the threshold defining what it means to be radicalised.

This result is to be expected, because radicalisation in the UK is — thankfully — a very rare phenomenon, and the people being input to the simulation are "normal" people who one would only expect to become radicalised if they are heavily exposed to a radicalising setting. But with only "normal" people in the model, no radicalising settings appear.

One way to establish how likely it is that a radicalising setting or a radicalising person appears in the model might be to run the simulation multiple times until a radical appears, and then to calculate how likely an occurrence this is based on the number of simulations run. However, a far simpler way is to look at what values for x_1, x_2 and x_3 would produce a radicalised person.

Let us define X_1, X_2 and X_3 to be independent, identically distributed random variables distributed $N(0,1)$, representing levels of SPI, self-control and exposure to radicalising moral contexts respectively. Then using the definition of radical as being someone with a propensity over 0.1228, we can calculate what values X_1, X_2 and X_3 would need to hold:

$$p = 1 - \left(\frac{1}{1 + 0.1228e^{-6.91+0.25X_1-0.1X_2+0.15X_1X_2+0.69X_3}}\right)^{8.14} \geq 0.1228$$

By rearranging this equation we have:

$$-6.91 + 0.25X_1 - 0.1X_2 + 0.15X_1X_2 + 0.69X_3 \geq -2.0243479$$

From this it is possible to establish what X_1 and X_2 values would be required for somebody to become a radical without any exposure to radicalising moral contexts (i.e. $X_3 = 0$), and thus how likely it is that someone with these X_1 and X_2 values appears in the model.

When $X_3 = 0$, for a person to be a radical they require X_1 and X_2 values such that

$$0.25X_1 - 0.1X_2 + 0.15X_1X_2 \geq 4.886.$$

As X_1 and X_2 are both random variables from a standard normal distribution, $0.25X_1 - 0.13X_2$ is also a normally distributed random variable, with mean $\mu = 0.15$ and variance $\sigma^2 = 0.0725$. However X_1X_2 has a "product-normal" distribution, which has characteristic function $\phi_{X_1X_2}(t) = (1+t^2)^{-1/2}$ (Oberhettinger, 1973). From this we can calculate the characteristic function of random variable $Y = 0.25X_1 - 0.1X_2 + 0.15X_1X_2$, but calculating $P(Y \geq 4.886)$ from this characteristic function is not possible analytically. However this is not necessary for the present study, which merely seeks to find out the approximate order of magnitude of $P(Y \geq 4.886)$. This can be achieved well enough simply by calculating $P(0.25X_1 \; - \; 0.1X_2 \; \geq \; 4.886)$, as for such an extreme value as 4.886 the contribution of the interaction term $0.15X_1X_2$ will be very small since there will be very few occasions where $0.25X_1 - 0.1X_2 + 0.15X_1X_2 \geq 4.886$ while $0.25X_1 \; - \; 0.1X_2 \; < \; 4.886$.

The probability that $0.25X_1 - 0.1X_2 \geq 4.886$ is equal to:

$$
\begin{aligned}
P(0.25X_1 - 0.1X_2 \geq 4.886) &= P\left(Z \geq \frac{4.886 - 0.15}{\sqrt{0.0725}}\right) \\
&= P(Z \geq 17.59) \\
&\approx 1.469 \times 10^{-69}
\end{aligned}
$$

This is a value which, even across a world population of 7 billion people, would never be expected to happen.

However, one does not expect there to be zero exposure to radicalising settings for a radicalised person to appear, making such unlikely values for X_1 and X_2 unnecessary. Perhaps a more sensible approach therefore is to ask what level of exposure to radicalising settings is required to turn someone in the most extreme 1% of X_1 and X_2 values into a radical? This is a far more important question for testing the realism of the model, as a person in the top 1% for both X_1 and X_2 would appear on average one time in 10,000, meaning there are approximately 6,400 such individuals in the UK. As the number of UK citizens sufficiently radicalised to join terrorist group Daesh in Syria is estimated to be in the hundreds (Neumann, 2015), this is a reasonable figure with which to work.

Individuals in the top 1% for both X_1 and X_2 will have $X_1 \geq 2.326$ and $X_2 \leq -2.326$. Putting these values into the equation above gives

$$-6.91 + 0.25(2.326) - 0.1(-2.326) - 0.15(2.326)(-2.326) + 0.69x_3 \geq -2.0243$$

giving $X_3 \geq 7.08$. This again is extremely rare, appearing with a probability of 7.2×10^{-13}.

At this point it can be concluded that in adapting the model so that it describes radicalisation instead of normal crime, the parameters in version one of the radicalisation model have been pushed so much to the extreme as to make radicalisation virtually impossible, which we know not to be true. This suggests that the parameters need to be adjusted further in order to make the radicalisation model realistic.

6.1.2 An alternative approach to parameterisation

The previous attempt to choose realistic parameters for the radicalisation model proved to be unsuccessful, as the probability of radicalisation happening to anyone at all was far too low. An alternative approach to parameterising the model therefore needs to be found.

The way that it was established that the radicalisation model was unrealistic provides a good starting point, as we can ensure that a realistic number of people with X_1 and X_2 values in the top percentile become radicalised. For instance, let us suppose that of these 6,400 most cognitively susceptible people in UK society, if they become exposed to a setting in the top 5% of radicalising settings they themselves become radicalised. As X_3 follows a standard normal distribution, this means that we would require $X_3 \geq 2.5758$ to make somebody with $X_1 \geq 2.3263$ and $X_2 \leq -2.3263$ become radicalised. This provides a boundary condition of:

$$\beta_0 + \beta_1(2.3263) + \beta_2(-2.3263) + \beta_{12}(2.3263)(-2.3263) + \beta_3(2.5758) \geq -2.0243479$$

We can then specify other logical conditions to ensure that the values chosen for β_0, β_1, β_2 and β_3 produce a model with realistic results. For example, β_1 and β_3 should both be greater than 0, because as susceptibility to peer influence and exposure to radicalising settings increase, we would expect an individual's propensity to commit terrorist attacks also to increase. Similarly, β_{12} should also be greater than 0 because Meldrum et al.'s finding that the effect of susceptibility to peer influence on delinquency is stronger at higher values of self-control is likely to be applicable to radicalisation as well as to criminality. However, β_2 should be less than 0, because self-control on its own is negatively correlated with the propensity to commit severe crimes. In addition, as it has already been concluded that the influence of morality is greater in the radicalisation process than the influence of self-control, there should also be $|\beta_2| < |\beta_1|$ and $|\beta_{12}| < |\beta_1|$. Finally, there needs to be a condition for β_0: as the logic behind the original choice of $\beta_0 = -6.91$ still stands, this parameter will remain unchanged.

These conditions are not overly restrictive, and there still remains a great deal of flexibility in the choice of parameters. Ultimately it is only through the collection and analysis of empirical data concerning the relationship between susceptibility to peer influence, self-control, exposure to radicalising settings and actual radicalisation that one can hope to estimate these parameters with any degree of accuracy, but for this theoretical model these steps of logic provide enough of a guide to enable the radicalisation simulation to be parameterised and compared with the model describing the development of criminality. For this second attempt at parameterising the radicalisation model the values chosen were $\beta_0 = -6.91$, $\beta_1 = 0.9$, $\beta_2 = -0.45$ $\beta_{12} = 0.05$ and $\beta_3 = 0.8$, which gives

$$\beta_0 + \beta_1(2.3263) + \beta_2(-2.3263) + \beta_{12}(2.3263)(-2.3263) + \beta_3(2.5758) = -1.979$$

6.1.2.1 Behaviour of Radicalisation Model Version Two

As with the previous version of the radicalisation model, when the simulation was run for 260 time-steps with the default people and settings inputs, nobody in the model became radicalised and no radicalising settings emerged. This was the case when 100 and 500 people were input into the model. The maximum propensity achieved by anyone in the model over the whole simulation was 0.0456 (achieved by Person 472 at time $t = 1$), which is below the radicalisation threshold of 0.1228, but not so far below it as to suggest that radicalisation would be an impossibility. These results are entirely consistent with what one would expect from the simulation, as radicalisation in UK society is a very rare occurrence.

In order to test whether this version of the radicalisation model is producing results that are more realistic than the first version we need to create a situation where a radical appears and see how (and whether) radicalisation spreads, which can be achieved by planting a person with sufficiently extreme values for SPI and self-control into the model. This was done by increasing the SPI of Person 472 by 1, which makes their propensity at time $t = 1$ greater than 0.1 and forces the process of the emergence of radicalising settings to begin.

When this simulation was run for 260 time-steps, all 500 people in the simulation had a propensity of 1 by time $t = 3$. This is clearly highly unrealistic. On closer examination of what is occurring during the first three time-steps, at time $t = 2$ nine settings have a radicalisation level of 0.103, which then has the effect of making 471 of the 500 people officially "radical" (i.e. they have propensity greater than 0.1228). In the next time-step total radicalisation has spread to everybody. This suggests that the value for β_3 is far too high, as a relatively small number of slightly radicalising settings has had an overwhelming impact.

The explanation for the model behaving in this way is that when criminogenic exposure is converted into a z-score to give a value for x_3 the value used for the variance is very low (the sample variance calculated after some trial simulations is $s^2 = 0.000006$), which results in disproportionately high values for x_3 for anyone who has visited a setting with even a low radicalisation level. This is an inevitable by-product of the rarity of radicalised people and radicalising settings, which makes the distribution of propensities among the population highly positively skewed but with a very low variance. This problem can be fixed in two ways: either the variance used to convert criminogenic exposure into a z-score is increased, or β_3 is reduced. As increasing the variance is not statistically justifiable, it is preferable to reduce β_3. The question is, by how much?

In order to answer this question, the simulation was run with a number of lower values for β_3 in order to establish the effect of changing this parameter, and in particular what values of β_3 produce a model where one highly cognitively susceptible person does not cause all people in the model to become radicalised.

6.1.2.2 The Effect of Changing β_3

The radicalisation model was run for 260 time-steps using the default settings input and the 500 person input with Person 472 modified to force the emergence process to start. Values for β_3 were varied from $\beta_3 = 0.8$ (the value used in version 2) down to $\beta_3 = 0$.

Comparing the propensity levels of all people in the model and the number of radicals that appear for these different values of β_3 revealed that for values of β_3 of 0.0354 and above the average propensity level after 260 time-steps is greater than 0.99, and all 500 people become radicals. At the other end of the spectrum, for values of β_3 below 0.027 no people in the model are radicalised after 260 time-steps, and the average propensity level stabilises at approximately 0.0019.

When β_3 holds a value between these two bounds, the model behaves in rather more interesting ways, as can be seen from Figure 6.1. This graph shows the average propensity for severe crimes over all 260 time-steps for some β_3 values in this range, and from it we can see that the average propensity varies greatly over time between the different model versions, but ultimately stabilises around 0.02.

The number of radicals generated by the simulation after 260 time-steps for values

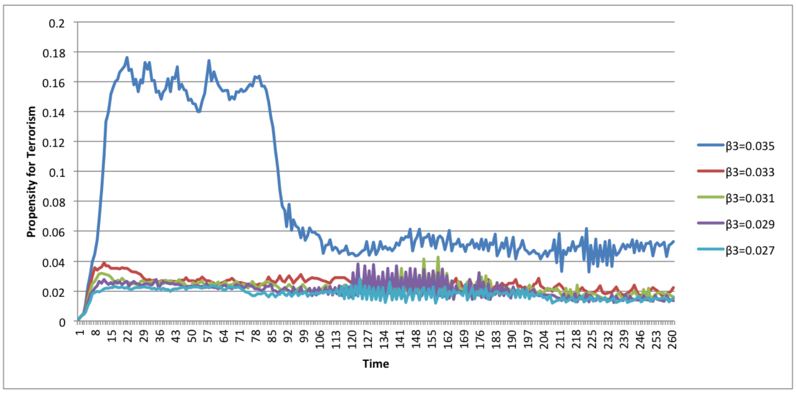


Figure 6.1: Average propensity for terrorism for the radicalisation model with different β_3 values when the simulation is run for 260 time-steps and seeded with one highly susceptible person.

of β_3 in this range also varies, as shown in Table 6.1. Of particular note from this table is the dramatic increase in the number of radicals present at the end of the simulation when the value of β_3 is increased only a very small amount above 0.035. This tells us that the amount of weight given to the $x_3(t)$ (exposure to radicalising settings) variable should not rise above this value, as when $\beta_3 > 0.035$ radicalisation is pervasive and the model becomes highly unrealistic.

Table 6.1: Number of radicals generated by the simulation at $t = 260$

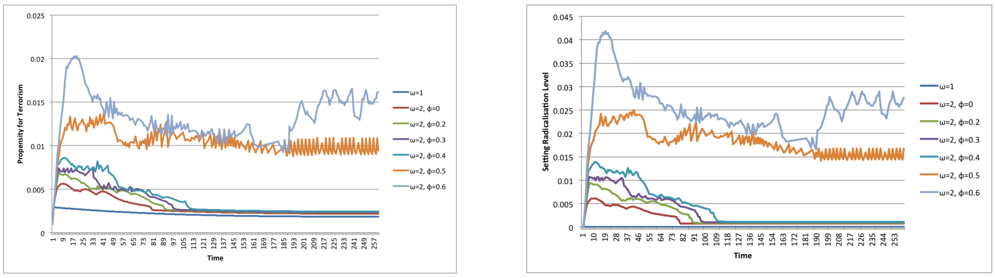
β_3	**Number of radicals**
≤ 0.0265	0
0.027-0.031	6
0.032	10
0.033	13
0.034	12
0.0345	26
0.035	42
0.352	417
≥ 0.354	500

6.1.3 Changing Environmental Factors

In Section 6.1 it was argued that the collective efficacy coefficient ω_j of each setting should be incorporated into the emergence transition in two ways: firstly by multiplying some function $f(\omega_j)$ with the average propensities of all people visiting the setting, and secondly as part of the emergence propensity threshold. It was decided that the function $f(\omega_j) = \omega_j^{\phi}$ for $\phi \in (0.1)$ would be a theoretically suitable function to use in the absence of primary data. This section explores the effects of choosing different values for ϕ and ω_j on the behaviour of the model.

The parameter ϕ has so far been left undefined (other than stipulating that it should be less than 1) because the model has only been run with the default settings input where all settings have a collective efficacy coefficient of 1. However, a further test of whether the radicalisation model is producing credible results would be to increase the collective efficacy coefficients of the settings and analyse whether the model produces more radicals, and if so how many more radicals. Translating this to the real world, increasing the collective efficacy coefficients of all the settings in the model would indicate a breakdown of local organisational structures and a lack of social control and cohesion, which one would expect to make radicalisation a more likely occurrence, although still relatively rare while collective efficacy levels remain moderate. However if the collective efficacy coefficients became large enough they would represent such a breakdown of social structures (for instance as might be found in a place affected by war) that radicalisation might be seen significantly more frequently, as has sadly been observed in recent years in war-torn Syria.

In order to observe how the model assesses radicalisation might spread in more socially disorganised environments, a credible value for ϕ must be chosen. To determine such a value the model was run for 260 time-steps with the default 500 people input (i.e. without the planted highly susceptible individual) and a settings input where all settings have $\omega_j = 2$, and with a variety of values for ϕ to explore the impact of changing this parameter. A value of $\beta_3 = 0.028$ was used, as the previous section has shown that when all settings have collective efficacy equal to 1 this value for β_3 generated a credible result in terms of the number of people who become radicalised when one highly cognitively susceptible person forms part of the input.



(a) Propensities for Terrorism

(b) Setting Radicalisation Levels

Figure 6.2: Average propensity for terrorism and average setting radicalisation levels for the model over 260 time-steps with different ϕ values with the collective efficacy of all settings equal to 2.

Figure 6.2 shows the results of this test. From the graphs in Figure 6.2a it can be seen that the line showing the average propensity when all settings have collective efficacy equal to 1 is lower than all the other lines, and thus that in all cases a collective efficacy coefficient of 2 results in higher propensities for terrorism overall. Figure 6.2b shows the same result is true for the radicalisation levels of the settings. However, in both cases the difference between the line for $\omega_j = 1$ and those for $\omega_j = 2$ with ϕ between 0 and 0.4 is very small indeed after approximately 120 time-steps. A value of ϕ of 0.5 or 0.6 might therefore be more realistic, given that the literature discussed in Section 4.1.5 suggests that collective efficacy is a highly influential factor in determining whether people visiting a setting are likely to develop an increased propensity for crime (including terrorism).

An alternative way to compare these results is to count the number of radicals produced by the simulation after 260 time-steps, which is shown in Table 6.2. This table also suggests that ϕ needs to hold a value of at least 0.5 before the effects of doubling the collective efficacy coefficients for all settings actually has an impact on whether people become radicalised. It is therefore proposed that a value of $\phi = 0.5$ will be used in the model.

6.1.3.1 The Effect of Extreme Environments

One similarity between the radicalisation model and the criminality development model is that they are both describing the process of the breakdown of moral re-

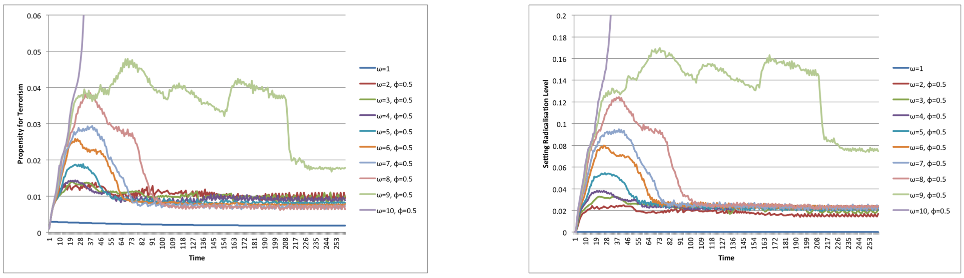
Table 6.2: Number of radicals at $t = 260$ for different ϕ values.

Test	**Number of radicals**
All settings with $\omega_j = 1$	0
$\omega_j = 2$, $\phi = 0$	0
$\omega_j = 2$, $\phi = 0.2$	0
$\omega_j = 2$, $\phi = 0.3$	0
$\omega_j = 2$, $\phi = 0.4$	0
$\omega_j = 2$, $\phi = 0.5$	4
$\omega_j = 2$, $\phi = 0.6$	5
$\omega_j = 2$, $\phi = 0.7$	5
$\omega_j = 2$, $\phi = 0.8$	500

straint. However because the threshold for what it means to be a radical is much higher than the threshold for having sufficient propensity to carry out petty crime, it is difficult to see the subtleties of the process in the radicalisation model. Radicalisation is very rare in UK society, and the individuals in the model who do become radicalised are highly cognitively susceptible to it, making the influence of environmental factors relatively minor. However what if the model's geographical input was altered so that it represented an environment where weak levels of morality were pervasive? Would radicalisation here spread in the same way as criminality, with individuals who are far less cognitively susceptible being affected?

This can be tested by altering the value of ω_j. If ω_j holds high values for all settings in the model, this would represent a lawless society that has experienced a complete breakdown in collective efficacy, such as might be seen in an unstable war-torn country such as Syria. Testing the behaviour of the radicalisation model when ω_j holds higher values would therefore tell us how radicalisation might spread in such an environment.

Figure 6.3 shows the results of running the simulation over 260 time-steps when all settings have high values for ω_j. From these graphs it is clear that as ω_j increases the average radicalisation levels of the settings increase as well at the start of the simulation, with a similar pattern also visible for the average propensities. However, for all but the very highest values of ω, after approximately 40 time-steps the propensities and radicalisation levels start to decrease again until the averages become almost indistinguishable from each other. This result is also visible when we examine the number of radicals that the simulation produces at time $t = 260$ for the different values of ω, shown in Table 6.3. For $\omega \leq 8$ there is very little change in the number of radicals, but when ω rises above this value radicalisation becomes an epidemic.



(a) Propensities for Terrorism **(b)** Setting Radicalisation Levels

Figure 6.3: Average propensity for terrorism and setting radicalisation levels for the model over 260 time-steps with high values for the collective efficacy coefficients of all settings.

Table 6.3: Number of radicals at $t = 260$ for different ω values.

Test	**Number of radicals**
All settings with $\omega_j = 1$	0
$\omega_j = 2$	4
$\omega_j = 3$	4
$\omega_j = 4$	2
$\omega_j = 5$	2
$\omega_j = 6$	2
$\omega_j = 7$	2
$\omega_j = 8$	2
$\omega_j = 9$	7
$\omega_j = 10$	500

Are these results realistic? Collective efficacy as it has been included in the model is a theoretical parameter, so the real world impact of changing it to the extent that we have done here cannot be determined. Several studies have used an empirically derived measure of collective efficacy in their research, such as Sampson (2004) and Wikström and Treiber (2009) — but, as has already been mentioned in Section 4.1.5, no research has yet been conducted into what precisely is the mechanism through which low collective efficacy causes a setting to become more criminogenic or more radicalising. This remains a question to be answered, and it is one that can only be answered using traditional social science methods. Once this question has been answered, the realism of the results produced by the radicalisation model when run in an extreme environment can be better assessed.

6.2 The Final Model

6.2.1 Transitions in the Radicalisation Model

We are now in a position to put forward a complete model simulating the radicalisation process. This model is a modified version of the original model for criminal propensity development, and it produces credible results in terms of the number of people likely to become radicalised in different situations. For this model the following functions are used for the transitions:

Exposure: After the exposure transition the propensity p of person i for terrorist activity at time t is:

$$p_i(t) = 1 - \left(\frac{1}{1 + 0.1228 e^{-6.91 + 0.9 x_1(t) - 0.45 x_2 + 0.05 x_1(t) x_2 + 0.028 x_3(t)}} \right)^{8.14}$$

where the x_is are realisations of random variables X_1, X_2 and X_3 with distribution $N(0,1)$, which represent person i's susceptibility to peer influence, self-control, and exposure to radicalising settings respectively.

Emergence: After the emergence transition the radicalisation level r of setting j at time t is:

$$r_j(t) = \frac{\omega_j^{0.5}}{n} \left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t) > \tau_1 \\ \& \ p_i(t) > \varepsilon / \omega_j}} p_i(t) \right)$$

for $\tau_1 = 1$ hour and $\varepsilon = 0.1$.

As this is a theoretical model that has not been parameterised using empirical data there remains uncertainty around what values the parameters should hold, however this version of the model satisfies the following criteria:

- With the default people and settings inputs nobody becomes radicalised;
- When an unusually cognitively susceptible person is introduced to the model, a small number of other people become radicalised;
- When the collective efficacy coefficients of the settings are doubled a small number of people become radicalised.

The complete description of the full radicalisation model is at Appendix A.

6.2.2 Model Validation

As with the criminality development model constructed in Chapter 5, the radicalisation model will be validated against a list of stylised facts. The stylised facts suggested in Section 3.2.6 were as follows:

1. The agents in the model should be heterogeneous with regard to radicalism;
2. The distribution of propensities for terrorism across the population should be much more positively skewed than the distribution of propensities for crime;
3. An individual's propensity for terrorism can increase or decrease over time;
4. A steady state for the system overall should not be reached;
5. Radicalising moral contexts (i.e. settings) should be far rarer than criminogenic moral contexts.

The model inputs for the validation comprise 500 individuals with one highly cognitively susceptible individual, and all settings have $\omega_j = 1$.

1. Heterogeneity of agents

Figure 6.4 shows the propensities for terrorism of the 500 individuals in the model at the end of the simulation. From this graph it is clear that the agents have different propensities for terrorism, so this stylised fact is replicated.

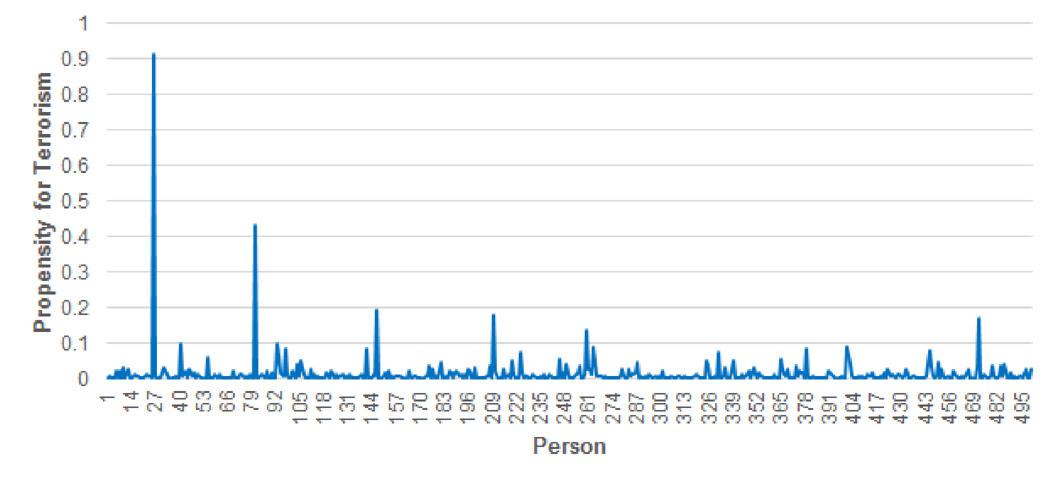


Figure 6.4: Graph showing the propensities for terrorism for the radicalisation model with one highly susceptible individual at time $t = 260$ (standardised)

2. Distribution of propensities for terrorism

A histogram showing the distribution of propensities for terrorism compared with the distribution of propensities for crime from different versions of the criminality development model is at Figure 6.5. The propensities for all four model versions have been standardised so that they have mean 0 and variance 1 in order to facilitate comparison between the models. A sample of 100 individuals from the radicalisation model was used to construct the histogram in order to compare the distribution of propensities with the criminality development model (which was run with 100 individuals).

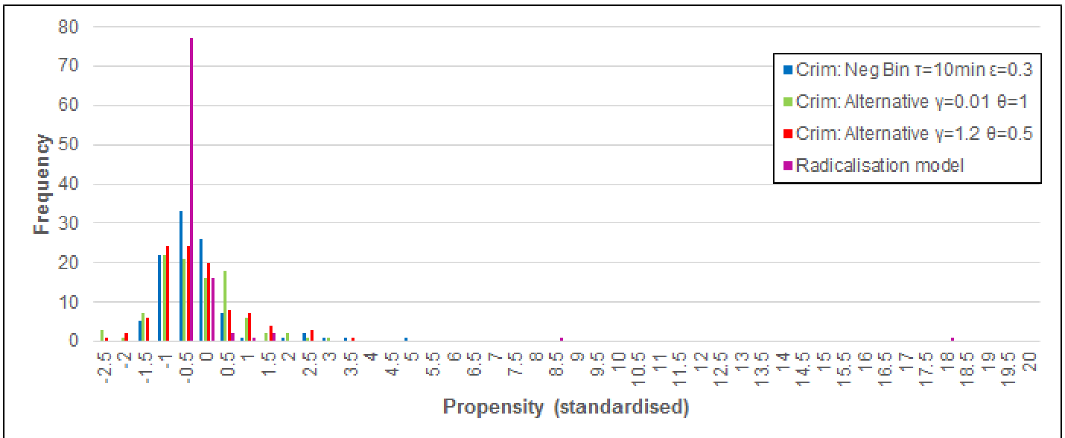


Figure 6.5: Histogram showing the distribution of propensities for crime compared with the distribution of propensities for terrorism at time $t = 260$ (standardised)

From this histogram it can be seen that there is much less variability in propensities for terrorism than there is in propensities for crime, with nearly all individuals in the model having lower than average propensity for terrorism. There are a small number of individuals with extremely high propensity for terrorism, while no such individuals exist for any of the criminality development model versions. There is a positive skew for all datasets, although it is not noticeably more positive for the radicalisation model than it is for the criminality development models. However the number of individuals with standardised propensity less than 0 is significantly greater for the radicalisation model: 394 out of 500 individuals (78.8%) for the radicalisation model, versus between 54% and 60% for the different criminality development model versions. It can therefore be concluded that this stylised fact is satisfied by the model.

3. Change in propensity for terrorism

The graph at Figure 6.6 shows the propensity for terrorism over time of a random 10 individuals in the model. From this graph it is clear that the propensities of all individuals in the model can both increase and decrease.

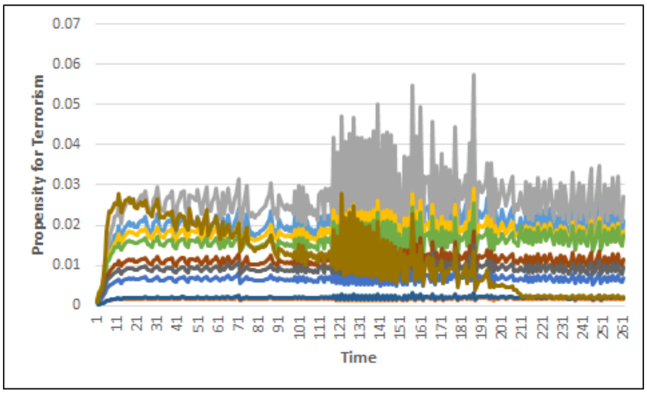


Figure 6.6: Propensity for terrorism over time of 10 people in the model

4. Lack of steady state

Figure 6.6 also shows that for the radicalisation model no steady state has been reached, and that individual propensities continue to change at the end of the simulation.

5. Rarity of radicalising settings

Table 6.4 shows the number of settings with zero versus non-zero radicalisation level at the end of the simulation, compared with the number of settings with zero or non-zero criminogenity level at the end of the negative binomial version of the criminality development simulation. (The versions of the criminality development model using the alternative function in the exposure transition give unbounded values for criminogenity, meaning that the concept of "zero criminogenity" cannot be defined and thus these versions of the model cannot be used in this comparison.) Residences were excluded from this analysis, as the radicalisation model has 500 residences versus the criminality development model only having 100.

Table 6.4: Number of settings with the given radicalisation or criminogenity levels at the end of the simulation

Radicalisation or Criminogenity level	**Radicalisation Model**	**Negative Binomial Criminality Model**
0	42	24
$0 < x \leq 0.1$	0	13
$0.1 < x \leq 0.2$	5	16
$0.2 < x \leq 0.3$	3	0
$0.3 < x \leq 0.4$	2	2
$0.4 < x \leq 0.5$	0	0
$0.5 < x \leq 0.6$	3	0
Total	**55**	**55**

The table shows that for the radicalisation model 42 out of the 55 non-residential settings have zero radicalising influence, while only 24 of the 55 settings have zero criminogenic influence in the criminality development model. The radicalisation model therefore does satisfy the stylised fact. However, it should also be noted that there are very few settings that have greater than 0.2 criminogenic influence (only 2 out of 55), while 8 of the 55 settings have greater than 0.2 radicalising influence. This suggests that where radicalising settings *do* exist they tend to be highly radicalising, while criminogenic settings tend to be only weakly criminogenic. Further research would be needed to determine whether this finding is true in the real world, but if not then it suggests that both models need further refinement.

Overall the radicalisation model has been found to satisfy all five of the stylised facts, although stylised facts 2 and 5 in particular raise additional questions as to what precise phenomena the model should be aiming to replicate.

6.3 Answering the Research Question

It is now possible to return to the main research question to be answered in this thesis, which was first introduced in Section 2.4.3: are the radicalisation and criminal propensity development processes indistinguishable? Over the past three chapters two separate computer simulations based on the IVEE framework have been developed: one to mimic how people develop the propensity to commit crime in general, and one focussing on radicalisation. By comparing the mechanisms in the two simulations and the results they produce we can explore how similar or different these two processes actually are.

For the criminality development process the model created used two different types of state — people and settings — and two transitions that link the states together which either cause a change in a person's propensity for crime or a setting's criminogenity. For the radicalisation process the model developed followed the same basic structure as the criminality development model. It used the same method to generate the activity fields, f_{ijk}, as no fundamental differences between radicalisation and criminality development were identified in the literature with regard to how selection mechanisms contribute to the overall process. The differences lie in the specific parameters used in the transitions.

For the criminality development model the two transitions emergence and exposure, can be written as the following equations:

Emergence (criminality development):

$$c_j(t) = \frac{\omega_j}{n}\left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t)>\tau_1 \\ \& \; p_i(t)>\varepsilon}} p_i(t)\right)$$

Exposure (criminality development):

$$p_i(t) = 1 - \left(\frac{1}{1+0.1228e^{-0.23+0.25x_1(t)-0.13x_2+0.15x_1(t)x_2+0.69x_3(t)}}\right)^{8.14}$$

where changing the values of τ_1 and ε or the method of calculating x_3 alters the final values of the propensities, but it does not affect who ultimately ends up with relatively high or low propensities (i.e. the basic shape of the propensity graph at $t = 260$).

For the radicalisation model these equations became:

Emergence (radicalisation):

$$r_j(t) = \frac{(\omega_j)^{0.5}}{n}\left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t)>1 \text{ hour} \\ \& \; p_i(t)>0.1/\omega_j}} p_i(t)\right)$$

Exposure (radicalisation):

$$p_i(t) = 1 - \left(\frac{1}{1+0.1228e^{-6.91+0.9x_1(t)-0.45x_2+0.05x_1(t)x_2+0.028x_3(t)}}\right)^{8.14}$$

While the descriptions of the model have both similarities and differences, the real test of how similar these processes are comes from comparing the behaviour of the two models. It is of course expected that radicalisation is a far rarer occurrence than it is for someone to development a strong propensity for crime; but how do the two processes compare when the radicalisation model is applied to a chaotic, war-torn environment? Is there a tipping point after which radicalisation as a process essentially behaves the same as criminality propensity development?

In order to explore this further a comparison was conducted between the propensities at $t = 260$ for the criminality development model with $\tau_1 = 10$ minutes and $\varepsilon = 0.2$, and the radicalisation model. The same 500 person input files were used for both models, and the same setting inputs with the exception that for the criminality development model all settings have $\omega_j = 1$ while for the radicalisation model all settings have $\omega_j = 9$. The propensity levels for all 500 people at time $t = 260$ are shown in Figure 6.7.

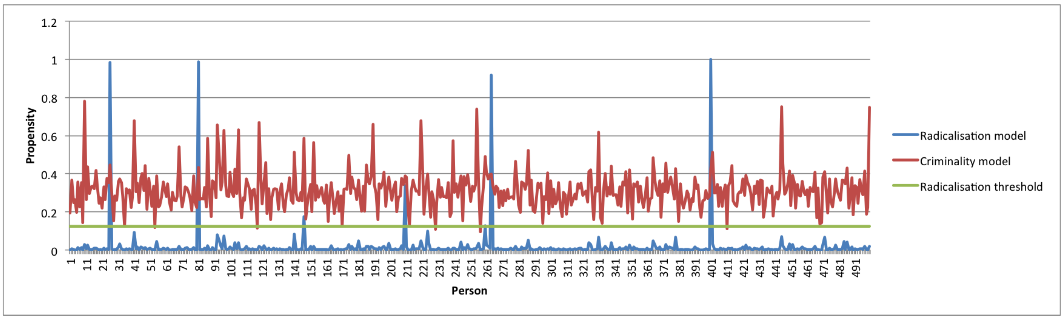


Figure 6.7: Propensities for the radicalisation model run in an extreme environment ($\omega_j = 9$) and the criminal propensity development model in a standard environment ($\omega_j = 1$) at time $t = 260$

The first observation to be made from comparing the graphs is how different in shape they are. The two datasets actually have a very similar variance ($\sigma^2 = 0.0096$ for the criminality development model and $\sigma^2 = 0.0078$ for the radicalisation model), but this similarity hides the stark difference that for the radicalisation model the majority of people have a very low propensity for terrorism while just a few are extreme outliers, whereas propensity is far more evenly distributed for the criminality development model. This is illustrated better by the histograms in Figure 6.8, which show clearly that the propensities in the criminality development model are approximately normally distributed, while for the radicalisation model they are heavily skewed.

A second observation of interest from the graphs in Figure 6.7 is that those indi-

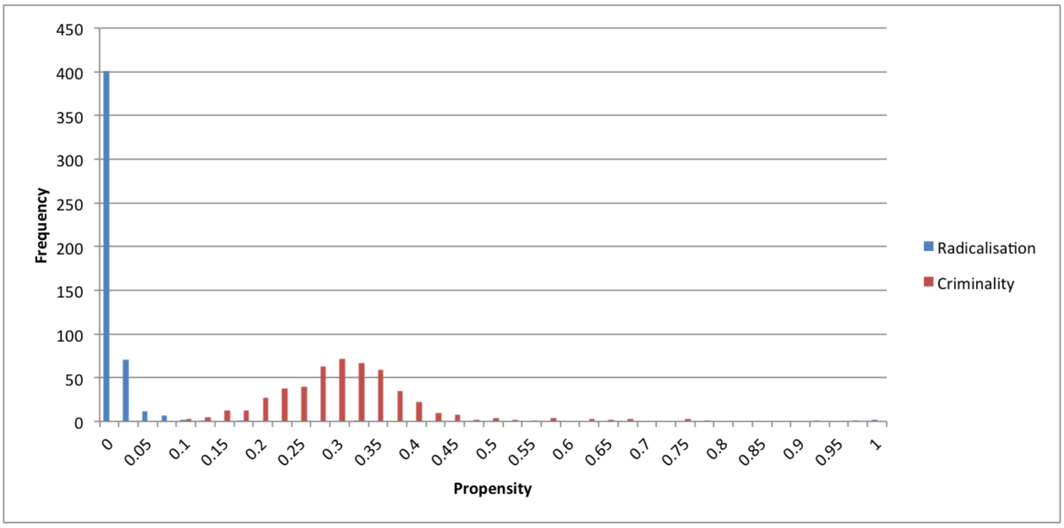


Figure 6.8: Histogram showing the distribution of propensities for crime or terrorism for the two models at time $t = 260$

viduals with the highest propensities for terrorism in the radicalisation model are not the same individuals who have the highest propensity for crime in the criminality development model; indeed the correlation between the two datasets is only 0.222. To explain why this might be it is worth examining the individual attributes (SPI and self-control) of the individuals with the highest propensity levels at time $t = 260$ in more detail to understand how much influence these attributes actually have. This analysis reveals that those with the highest propensities for terrorism are more likely to have very high levels of SPI and low levels of self-control, while those with a higher propensity for crime are more likely to have high levels of SPI and also higher than average levels of self-control (it is worth noting here that in general self-control is weakly negatively correlated with propensity for both models). These differences go some way towards explaining why it is that the individuals with the highest propensities are not the same for both models. An additional difference between the two models comes from comparing the criminogenity levels and radicalisation levels of the settings at time $t = 260$; as with the propensities, there is a low correlation between the two (only 0.182).

6.3.1 Summary

To summarise, comparing the outputs of the criminal propensity development model with the radicalisation model running in a socially unstable environment has revealed that:

- The two models produce different distributions of propensities across the population, with the distribution for the criminal propensity development model being approximately normal and that for the radicalisation model being highly positively skewed;
- The individuals with a high propensity for normal crime are not the same people as those who would become radicalised in an unstable environment;
- The settings with the highest radicalising influence are not the same as the most criminogenic settings.

Therefore, from the analysis undertaken on the respective models representing the criminality development and radicalisation processes, it can be concluded that even when the radicalisation is taking place in a war-torn, highly socially disorganised environment, the two processes are not at all alike. However the mechanisms connecting the components in each process are the same: the differences arise purely as a result of the parameters chosen.

6.4 Extension to Include Virtual Settings

The importance of "virtual settings" in how people gain exposure to radicalising moral contexts is one that has not yet been considered in this thesis, but should not be ignored: modern terrorist organisations such as Daesh have shown themselves to have a sophisticated knowledge of how the internet can be used to reach out to potential recruits, with promotional videos of their atrocities uploaded to YouTube and advertised via supportive Twitter users (Irshaid, 2014). Therefore if the models are ever to be of potential use to practitioners in future they need to be sufficiently flexible to allow for online radicalisation to happen. This short section explores how virtual settings could be incorporated into the models, but stops short of doing so in practice as it is not of direct relevance to the primary research question.

The literature on how influential the internet is as part of the radicalisation process is sparse, as most studies examining the internet's role have focussed on the "supply" side of what terrorist material is available to view online, rather than the "demand" side of what effect such material has on those who come into contact with it (Edwards and Gribbon, 2013, p. 41). However some research has been carried out concerning the role of the internet in 15 individual cases of radicalisation as part of a RAND study (Von Behr et al., 2013). The cases showed considerable variation according to each individual's age and role in their respective terrorist organisations: for instance, an older recruiter interviewed for the study needed face-to-face meetings to sell his ideas during the 1990s, but in the 21st century he could used the internet for the same purpose and so reach a wider audience. The younger interviewees used a wider range of online tools, such as BitTorrent for sharing information, and social media sites for fostering a sense of community. On this last point, previous research had also noted that the internet provides a means by which disparate people with extreme views can find each other, allowing them to encourage each other without their views being challenged — essentially acting as an echo-chamber (Post, 2005, p. 10).

The ways in which terrorist recruiters use the internet for radicalisation must be put into context with internet use more generally, as this itself varies enormously across the population. Kozinets (2009) has studied general online culture, and he has observed that people become integrated into online communities via a gradual process. This process begins with a person browsing — that is, merely reading about the subject from a passive perspective. They then progress to being "lurkers", where they will observe the interactions of others in the online community but not participate themselves. After some time they may then decide to take part in discussions themselves, starting out as "newbies" before eventually becoming "insiders". However the process of online integration is not a conveyor belt, and the people who get to the end of the process and become "insiders" are very much in the minority.

Indeed, studies including Berger and Strathearn's research into online extremism have found evidence to support the "90-9-1 rule", which suggests that 90% of users of online discussion groups are passive, 9% are somewhat engaged, and 1% drive most of the discussion (2013).

So what does all this tell us about the radicalisation process online? The cases considered in the RAND study provide further support for the IVEE framework as a means of synthesising what we know about radicalisation, as the individual journeys undertaken by each of the cases can still be interpreted in terms of IVEE. As with physical settings, people can either happen across radicalising websites accidentally or look for them deliberately, and the likelihood of them doing either depends on self- and social selective factors. And, as with physical settings, when somebody does become exposed to a radicalising narrative on a website, whether it has an effect on their morality depends on their personal cognitive susceptibility: indeed one of the RAND study's cases observed that the echo-chamber effect depends on the individual consumer in question, what they are seeking, and how far along the radicalisation journey they are (Edwards and Gribbon, 2013, p. 45).

As online radicalisation is compatible with IVEE it follows that it can be integrated into the model; the question is how best to do so. In the original version of the model the attributes of the physical settings are their location, size, collective efficacy, and radicalisation level — the latter being a dependent variable and the others being constant over time for each setting. For virtual settings there are no locations, and therefore no cost for a person to visit them — anyone with an internet-enabled device can visit any webpage with ease (with certain exceptions, such as those requiring membership or those forming part of the dark net). Also a webpage does not have a "size" as such, although some webpages attract many more visitors than others. The size variable can therefore be re-interpreted for virtual settings to make it represent a website's overall popularity. Collective efficacy can similarly be made applicable to online settings by re-defining it so that it takes into consideration the level of moderation attached to websites where people can post comments or update their status.

So far these attributes of settings do not pose a problem and can easily be reconfigured for virtual settings. However it is with the dependent variable — radicalisation level — where we find a difficulty. In the original model a setting's radicalisation level is calculated by taking into consideration the propensities of all the people who visit that setting. For a virtual setting there could be millions of visitors from anywhere in the world, meaning that for the radicalisation level of virtual settings to be calculated the simulation would have to cover the entire of the world's online population, and thus the whole simulation would have to cover the whole world. This is clearly infeasible. A similar problem arises when considering how many virtual settings should be incorporated into the model, as the size of the internet runs to several billion webpages.

An alternative approach would be rather than modelling each website separately, instead to merge virtual settings together into grouped entities according to their radicalisation level. The size of each entity would represent the overall popularity of *all* websites of that radicalisation level, so that if a website becomes more extreme this would be modelled by a change in the size of the relevant entities rather than a change in their radicalisation levels. This means that for virtual settings in the model the dependent variable would be size, and radicalisation level would be an independent constant.

The next question concerns time. A person can only be in one physical location at a time, and they are always located somewhere, so the total amount of time they spend at physical settings in the model has to sum to their total waking hours. However the total amount of time spent online varies from person to person, as does the length of time they spend visiting webpages of differing levels of radicalising influence. This does not pose a problem for the model from a theoretical perspective however, as the total amount of time spent online could be modelled as an individual attribute of each person. Research into the amount of time that people from different sociodemographic groups spend online and the types of sites visited has been carried out by Oxford Internet Surveys (2015) for a number of years, and this could be used to parameterise this part of the model.

Additionally, a new exposure transition would need to be devised in order to determine the level of influence that a webpage has on the individual viewing it. This would likely be similar to the negative binomial function used for physical settings, but with some added complexity regarding how the x_3 (exposure to radicalising narratives) parameter is calculated in order to integrate the 90-9-1 rule.

Extending the simulation to include virtual settings is thus entirely feasible, but would require certain questions to be answered first in order to ensure that the model could be correctly parameterised. These questions include how popular are websites of differing levels of extremism, how much of a radicalised person's time online is spent looking at extremist websites, and what is the relationship between an individual's cognitive susceptibility, the amount of time they spend on extremist websites, and their propensity for terrorism.

Chapter 7

Using the Models For Interventions

The past three chapters have sought to develop models describing the criminal development and radicalisation processes, test their credibility and stability, and finally put the models to use by generating an initial answer to the primary research question. This chapter seeks to further explore the potential utility of the models by investigating how interventions can be incorporated into the simulations. This will provide further insight into the research question, as it is possible that while the two development processes have been shown to be different, an intervention that is known to be effective against criminality development may also be effective against radicalisation, and vice versa. Equally it is also possible that an intervention that is effective against one process actually proves to be ineffective or counter-productive when used against the other.

Before exploring this question using the models, let us first consider the similarities and differences between the interventions most often used in the fields of counter-radicalisation and crime prevention from a real world perspective.

7.1 Counter-Radicalisation

7.1.1 Overview of UK Counter-Radicalisation Policy

In the UK counter-radicalisation falls under the remit of the Prevent strand of the government's wider counter-terrorism strategy, CONTEST. The Prevent strategy's aim is "to stop people becoming terrorists or supporting terrorism", which it attempts to achieve by meeting three objectives:

- Challenging the ideology that supports terrorism and those who promote it;
- Protecting vulnerable people; and
- Supporting sectors and institutions where there are risks of radicalisation (HMG, 2011).

There are a number of vehicles that have been put in place by the government to facilitate the achievement of these objectives. Legislation is one such vehicle, with the 2000 Terrorism Act allowing the Home Secretary to proscribe any organisation believed to be involved in terrorism (HMG, 2013). There is also the Channel programme, to which people identified as being vulnerable to radicalisation are steered. The Channel programme works alongside Prevent and describes itself as "a multi-agency approach to protect people at risk from radicalisation" (HMG, 2012, p. 4). Channel support can consist of a range of interventions, from engaging people in constructive leisure activities, to one-on-one mentoring (HMG, 2012, p. 21).

Prevent is not a "silver bullet"; those involved with its implementation, especially in the early days, admit to making mistakes and that delivery of the strategy was a process of trial and error (Chaudhury and Fenwick, 2011, p. 48). There were no benchmarks, templates, or best practices to follow. While counter-terrorism policies had been introduced previously in order to combat the threat of terrorism from separatist Northern Irish groups, these were generally restricted to target hardening measures. Counter-radicalisation policies were limited to those restricting press coverage of political groups with terrorist links such as Sinn Fein. The purpose of this was to limit the amount of publicity they received, publicity having famously been described by former Prime Minister Margaret Thatcher as the "oxygen" of terrorism (Lewis, 2005, p. 7). This restriction has long been rescinded, and while some have argued that it did damage Sinn Fein's reputation by denying it an aura of legitimacy (Wilkinson, 2006, p. 350), such a ban would be ineffective in today's internet age, and could even be counter-productive by forcing those in pursuit of information about the groups towards the terrorists' own propaganda.

The Prevent strategy was written in 2006 but was revised in 2011 following a review. The new version intended to address a number of controversial issues raised about Prevent in its original form, in particular that its allocation of regional funding according to the number of Muslim inhabitants made Muslim communities feel stigmatised (Richards, 2011; Kundnani, 2009). The strategy was also more generally criticised for impinging on civil liberties, and the government faced accusations that they were using Prevent as a means of spying on innocent people (Kundnani, 2009; Vidino and Brandon, 2012).

In an effort to address these issues the new version of Prevent encompasses violent extremism more generally rather than focusing on Islamism. Funding is now allocated to regions according to risk (as informed by intelligence) rather than purely demographics, making the new strategy more targeted (Vidino and Brandon, 2012, p. 18). It also looks more towards preventing extremist ideas rather than specifically preventing violence, the government's argument being that "some terrorist ideologies draw on and make use of extremist ideas which are espoused and circulated by apparently non-violent organisations" and "preventing radicalisation must mean challenging extremist ideas that are conducive to terrorism" (Choudhury, 2012, p. 25).

However despite these changes the Prevent strategy remains controversial among certain communities. As already discussed, the radicalisation process is not a simple conveyor-belt whereby people start by holding extremist views before migrating towards violent action, and the new strategy's focus on extremist ideas could take resources away from more effective interventions. The new strategy has also not solved the problem that when funding is allocated to a specific community that community feels stigmatised.

The controversies surrounding Prevent funding can have other unintended consequences. Some organisations have misrepresented themselves in grant applications to make their activities seem connected to Prevent when they are not, while some areas have exaggerated the level of jihadi activity in their communities to increase their likelihood of funding (Chaudhury and Fenwick, 2011, p. 57). Funding has also been a source of resentment between communities, for instance the Sikh Community Action Network complained in 2009 that Prevent was "a dedicated £80 million fund for the Muslim sector" while other religions were forgotten (Vidino and Brandon, 2012, p. 16). This increase in inter-community tensions may provide fuel for those trying to incite hatred.

Although the Prevent strategy faces criticism, the 2011 review does demonstrate a desire on the part of the government to learn from their previous mistakes and to make Prevent more effective as it matures. There is evidently still a need for more research into the effectiveness of counter-radicalisation measures in order to refine Prevent further.

7.1.2 Methods for De- and Counter-radicalisation

Counter-radicalisation is often used as a catch-all term, encompassing any project or intervention that aims to prevent people becoming terrorists. It covers de-radicalisation (turning an existing radical away from militancy), disengagement (where an existing radical simply ceases their involvement but may still hold extremist views), and preventing people becoming radicalised in the first place. It is therefore unsurprising that the literature shows an enormous variety of projects and interventions have been suggested for counter-radicalisation, from "soft" approaches such as encouraging debate in schools and communities (Korteweg, 2010; HMG, 2010), and encouraging social cohesion through youth groups (Innes, 2006;

Bhui et al., 2012), through to much harder approaches such as expelling radical preachers (O'Duffy, 2008; Korteweg, 2010), targeting "gatekeepers" (individuals who provide links to terrorist networks) for arrest (Taarnby, 2005), and bringing in longer or harsher prison sentences for terrorism offensives as a deterrent (Miller, 2013). These projects all share an aim of preventing people committing acts of terrorism, but they do so in a variety of different ways.

Examples of specific projects demonstrate the range of ways that organisations hope to stop people becoming radicalised. Simple methods such as promoting a counter-narrative include the theatre production "From one extreme to the other" that toured schools across the North West of the UK, reaching over 50,000 children from deprived areas, and the DVD-based lesson programme "Getting on together" that provides a robust critique of Islamic extremism (Vidino and Brandon, 2012, p. 13). Simple counter-narratives such as these serve two purposes: they seek to strengthen an individual's ability to make good moral decisions, and they discourage the individual from choosing to put themselves in a setting where they may be exposed to radical ideas. To relate this to the IVEE framework, counter-narratives seek to affect both an individual's cognitive susceptibility and self-selection. Groups putting out counter-narratives include government organisations such as the Home Office's Research, Information and Communications Unit (RICU), and charities such as Radical Middle Way, and the Strategy to Reach Empower and Educate Teenagers (STREET) (Briggs and Feve, 2013, pp. 42, 54).

This last group, STREET, engages in wider projects in addition to simply putting out counter-narratives. As one of the non-governmental organisations that participate in the Channel scheme, they offer individualised support, such as theological guidance and mentoring, and provision of welfare support (Barclay, 2011). In one case of an individual who had served time in prison for offences under the Terrorism Act, STREET's package of measures included career planning and access to new social networks to help him break ties with his old extremist associates (Barclay, 2011, p. 10). STREET's support can therefore also affect the social selection part of the IVEE process, by steering people away from radicalising settings who might otherwise have been swept along through their involvement in violent gangs or other forms of criminality. The key to STREET's success has been put down to both their theological knowledge and their cultural knowledge of the South London youths with whom they engage, which make their staff both credible and influential.

However not all projects initiated under the auspices of Prevent have been so successful. One high-profile example was a public debate in Tower Hamlets in 2007/2008 run by the Cordoba Foundation, who had received £38,000 in Prevent funding. The debate pitched Muslim Brotherhood speakers against pro-jihad speakers from Hizb-ut Tahrir. The pro-jihadists won the debate, resulting in 78% of the audience voting that "political participation had failed Muslims" (Vidino and Brandon, 2012, p. 16).

While this incident was clearly an unintended own goal, many other Prevent-funded projects have had less obvious but similarly negative consequences. Communities in receipt of Prevent funding are considered "suspect", and this can lead people in these communities to refuse to engage with Prevent (Kundnani, 2009, p. 25), resulting in those on the path to radicalisation not being given help to break out of the process. A lack of buy-in from communities also means that those who have already been radicalised may not be brought to the attention of the authorities. And even worse, if the communities feel alienated this could contribute to the process of radicalisation itself, by increasing the exposure people in that community have to any radicalising elements within it (Spalek et al., 2008, p. 17).

Overall, Prevent's credibility has suffered from the lack of assessment done on the impact of the projects that it is funding, both positive and negative. A Prevent-funded project that is not having a net positive effect is at best a waste of public money and at worst a contributor to the tensions that fuel violence and terrorism in the first place. That said, the 2011 Prevent strategy does include a section on evaluation, and it highlights that "performance monitoring and evaluation have been a weakness of the Prevent strategy. We cannot afford for that to continue." (HMG, 2011, p. 102). The strategy goes on to say that the government will carry out performance assessments and measure the impact of projects using such metrics as "the number of individuals no longer assessed as being vulnerable" (HMG, 2011, p. 102). However these performance assessments are unlikely to be published, making it difficult to know how well Prevent really is being evaluated. Apart from official government performance assessments the number of rigorous evaluations of counter-terrorism measures is woefully low, but those that have been done reveal that some interventions have had negative or displacement effects rather than positive effects (Enders and Sandler, 1993; Lum et al., 2006). Lum et al. recommend that more evaluations need to be carried out, looking at both the outcome effectiveness of interventions, and the social, political, economic and psychological effects.

If they can be demonstrated to have the potential to be effective, computer simulations such as those developed in this thesis may provide an additional tool that can be used to assist with evaluations in the future.

7.2 Measures to Prevent Criminality Development

Unlike radicalisation, there is no single government policy in place to prevent people from developing the propensity to commit crimes in general. And in seeking to prevent crime, many interventions are devised to target the "action" part of the process rather than the "development" part, meaning that they seek to alter situational factors through such means as target hardening, increasing surveillance, and reducing the temptation to break the law (Clarke, 1997). Ekblom (2005) gives an overview of measures that can be used to prevent crime by disrupting the "conjunction of criminal opportunity" and splits them into 11 categories which he places on a spectrum, with offender-oriented measures at one end and situational interventions at the other.

The development of an individual's propensity for crime is very much offender-oriented, making interventions at this end of the spectrum likely to have a significant impact on the process. However, interventions that are designed to be more situational in nature may also have an effect on criminality development. Examples come from across the whole of Ekblom's spectrum: for instance his third category consists of interventions that seek to tackle an individual's readiness to offend, including the control of stressors and motivators such as tackling unemployment. Unemployed individuals have more free time in which they may become exposed to criminogenic settings, and so providing a person with employment may reduce the likelihood that they develop the propensity to commit crime.

Similarly, Ekblom's fifth category of interventions affect an individual's decision to commit an offence, and therefore consists of measures targeting the "action" level of the causes of crime. This category includes deterrence measures such as imprisonment; imprisonment operates at the situational level by removing individuals with the propensity to commit crime from society for the period of their custodial sentence, making them unable to commit further crimes in that time. But it also affects the development of crime propensity more widely, as individuals who are incarcerated are less able to influence the morality of those on the outside.

Another example is at the situational end of the spectrum, from Ekblom's tenth category which consists of measures used by on-the-ground crime preventers, such as extra surveillance around likely targets. Increasing surveillance can also operate at the developmental level by making a person less likely to go to criminogenic settings, which will in turn prevent them becoming exposed to criminogenic influences and reduce the likelihood that their morality changes as a consequence.

However, as with counter-radicalisation schemes, crime prevention measures can have an array of unintended consequences. For situational crime prevention in particular one negative consequence can be displacement, which is where an offender will simply commit their intended crimes in a different location (Tilley, 2005, p. 5). Offender-oriented measures can also have their disadvantages, for instance if they target a group of people based on risk factors and in doing so they engineer association between fellow likely offenders. Certain measures such as "Stop and Search" also have ethical downsides similar to those affecting the Prevent programme, such as targeting “false positives” — people who have risk factors associated with criminality, but who do not themselves have a strong propensity for crime (Ekblom, 2005; Tilley, 2005).

In order to weigh up the pros and cons of implementing a particular crime prevention measure, a method called SARA has been developed and is commonly used to aid policy makers and practitioners (Karn, 2013, p. 20). The method consists of four stages: Scanning, Analysis, Response and Assessment, and it ensures that organisational and local community concerns surrounding the implementation of a particular initiative are included in the decision making process, and that initiatives undergo a thorough evaluation. The method has however been criticised for overly simplifying a complex process that rarely follows a linear path (Bullock and Tilley, 2009). The use of computer simulations to trial these measures prior to implementation may therefore provide an additional tool that can be used alongside SARA.

7.3 Mechanisms

This section takes four examples of interventions that focus on preventing crime and four that focus on preventing radicalisation, and considers in what way they affect the causal mechanisms in the process of propensity development. These eight interventions will then be incorporated into the computer simulations for crime propensity development and for radicalisation to enable their impacts to be simulated.

But first, it must be highlighted that — as with the simulations themselves — the way interventions will be incorporated into the models is theoretical. The implementation of actual interventions requires a substantial amount of project management and constant evaluation as to whether a programme is being delivered as intended and is having the hoped-for outcomes (Herman et al., 1987; Owen and Rogers, 1999). For the purpose of this thesis the interventions to be incorporated into the simulations will be assumed to have been implemented correctly and to be having the intended *direct* consequences. Based on this assumption the simulations will then be able to identify any *indirect* consequences.

The four interventions seeking to prevent criminality that will be incorporated into the model are:

- Early childhood interventions;
- Imprisonment;
- Overt surveillance;
- Reducing unemployment.

The four counter-radicalisation measures to be incorporated into the model are:

- General promotion of a counter-narrative;
- Targeted counter-narrative;
- Encouraging social cohesion through youth groups;
- Channel intervention on high-risk individual.

The aim of an *early childhood intervention* is to enhance the health and well-being of children aged from birth to five years, particularly for children born to families with significant risk factors such as being from disadvantaged communities or born to teenage mothers (Homel, 2005). Much research has been carried out into the efficacy of these measures, with several studies producing significant results: one example is the Elmira Project which ran in New York for two years, and involved home visits to 400 first-time young, single and/or low socio-economic status mothers. A follow-up after 15 years found that the children of the mothers visited had less than half as many arrests as the children of control mothers, and they also smoked and drank less and had fewer sexual partners (Olds et al., 1998). Other studies in different locations have seen similar successes, though some have noted that success is restricted to certain participant groups (for instance, the Elmira study saw positive outcomes only in high risk mothers), and others have highlighted the importance of commencing the intervention before the age of five (Homel, 2005). This suggests that the mechanism targeted by this intervention is the capacity of the children to exercise self-control — an attribute which, as discussed in Section 2.2.1, develops very early in life and may become impaired due to early exposure to toxins. This intervention will therefore be incorporated into the simulations by increasing the self-control of a group of individuals by a small amount before the time-loop starts.

The mechanism targeted by *imprisonment* was touched upon in the previous section but deserves further explanation. Imprisonment serves a number of purposes: it acts as a deterrent to those who already have the propensity for crime, it reduces crime directly by removing those with a propensity to offend from the streets and preventing them committing further offences while they remain in prison, it provides rehabilitation to the offender in the hopes that they will be less likely to reoffend in future, and it acts as a punishment in order to give victims a sense that justice has been done. The first and last of these have no impact on the mechanisms in the criminality development model, but the second and third do. By removing an individual with high propensity for crime from society for a time, they are less able to influence others, and the settings that they frequented before their incarceration will become less criminogenic as a result of their absence. And the rehabilitation provided by prison should (one hopes) reduce the propensity of an individual to commit crime in future. Imprisonment can therefore be incorporated into the simulations by adding an additional "Prison" setting, to which people can get sent for a certain number of time-steps if their propensity to commit crime becomes too high. While in prison, they will be exempt from the effects of the exposure transition, and the Prison itself will be exempt from the emergence transition; instead, the individual's propensity is decreased by a small amount each time-step.[1]

[1]This is obviously a simplification of the prison experience. A far larger version of the model could be built that includes several prisons and has a large prison population, enabling exposure and emergence to happen within prisons, and with the effects of prison rehabilitation programmes being far more nuanced. The way prisons are incorporated into the model in this thesis is meant for illustration purposes only, to provide an example of what the models can be made to do.

Overt surveillance acts partly as a deterrent and partly as an element of the criminal justice system. In its deterrence role, overt surveillance reduces the likelihood that an individual with the propensity to offend will go to a setting with the intention of doing so; in its latter role it increases the likelihood that an offender will be caught and then convicted. In both cases surveillance acts on an individual who already has the propensity to offend and therefore does not directly affect the criminality development process. However, the element of the process that overt surveillance does have an effect on is the collective efficacy of a setting, as a setting with a heavy police presence or that is obviously overlooked by CCTV cameras is unlikely to be thought of as a safe haven by offenders. This will therefore be incorporated into the simulation by decreasing the collective efficacy coefficients of a number of settings in the model.

Finally on the crime prevention front, the economic measure of *reducing unemployment*. This is not a specific crime prevention intervention per se, but it allows the flexibility of the model to be demonstrated, by providing a means of exploring the potential consequences of changing economic circumstances on crime. The implementation of this measure simply involves changing the proportion of employed and unemployed people input to the model.

The four counter-radicalisation measures have a different focus in terms of mechanisms. An example of the *general promotion of a counter-narrative* would be the material put out by the Home Office's Research, Information and Communications Unit (RICU) and charities such as Radical Middle Way (Briggs and Feve, 2013). These organisations distribute audio-visual messaging both on and off-line, and seek to reach as many vulnerable communities as possible. The aims of the counter-narratives are to strengthen individuals' knowledge of Islam (for narratives seeking to counter Islamist extremism) and their ability to think critically, so that they are less likely to become influenced by a radicalising narrative should they become exposed to one. Counter-narratives also seek to discourage their audiences from becoming exposed to radicalising influences in the first place. They therefore affect two mechanisms in the radicalisation process: they strengthen an individual's resistance to the influence of their peers, and they reduce the likelihood that individuals will choose to go to radicalising settings.

Organisations such as Radical Middle Way also deploy *targeted counter-narratives* by engaging in outreach with specific at-risk communities. The causal mechanisms that such programmes aim to disrupt are the same as for more general counter-narratives, but they would be intended to have a greater impact on a smaller number of people. The effects of the two different methods of promoting counter-narratives can therefore be compared using the models, by altering the extent to which an intervention reduces individuals' SPI and the attractiveness of radicalising settings, and the number of people affected by the interventions.

There are also a number of charities that *encourage social cohesion through youth groups*. One such example is the Active Change Foundation, based in Waltham Forest in East London. This charity carries out outreach and promotes counter-narratives, but it also has its own youth club bringing together local young people from an array of different ethnic groups. The youth club runs activities such as outward bound adventure training, careers advice, and bringing in invited speakers (Qadir, 2013; Active Change Foundation, 2015). Interventions such as these target several mechanisms: they affect self-selection by encouraging young people to spend their free time in a setting with high collective efficacy rather than in unmonitored locations, and in doing so they reduce the likelihood of exposure to a radicalising narrative. They also seek to strengthen the participants' resistance to peer influence. This intervention can be replicated in the model by declaring one of the youth clubs to be a more attractive setting than the others, and giving it a lower collective efficacy coefficient. Individuals who spend enough time at that youth club will also have their SPI lowered by a small amount.

The final counter-radicalisation measure is a *Channel intervention on a high-risk individual*. As discussed in Section 7.1, a Channel intervention can consist of a range of measures which vary from individual to individual, and can include such activities as encouraging people to participate in constructive pursuits, providing educational or careers support, or one-on-one mentoring and cognitive behavioural therapy (HMG, 2012). For the purposes of this illustration the Channel intervention that will be programmed into the model will be deemed to consist of one-on-one mentoring with psychological support that is intended to significantly reduce the individual's SPI and the likelihood that they will go to radicalising settings in the future. The Channel intervention takes place over a set number of time-steps when an individual's propensity to commit terrorism gets sufficiently high.

The next section will examine the outputs from the criminality development and radicalisation models when these interventions are incorporated.

7.4 Model Behaviour

7.4.1 Relative Effectiveness of Crime Prevention Measures

As with the testing of the computer simulations that was carried out in previous sections, the outputs coming from the versions of the model that include interventions must be compared with some default version. The default settings for the criminality development model were chosen to be the following:

- **People input:** 500 people spread evenly across the geographical area, with self-control and SPI normally distributed as previously, and with socio-demographic attributes evenly distributed. (This gives an unemployment rate of 33%.)

- **Settings input:** The usual settings input based on Peterborough are used, with the following distributions of collective efficacy coefficients: offices have $\omega_j = 0.6$, schools have $\omega_j = 0.8$, and all other locations have $\omega_j = 1$.

- **Emergence transition:** Thresholds of $\varepsilon = 0.2$ and $\tau_1 = 10$ minutes were used.

- **Exposure transition:** The negative binomial version of the exposure transition was used, with no time threshold and no exponential decay.

Table 7.1: Crime prevention measures

Intervention	**Changes to the default**
(1) Early childhood	(a) Universal: Increase all individual's self-control by 0.2 (b) Targeted: Increase the self-control of the cohort aged 16 at time $t = 0$ by 0.4
(2) Imprisonment	Add a "Prison" to the settings input. Individuals with propensity above 0.6 have a 50% chance of going to prison for 26 time-steps. While in prison their propensity reduces by 0.05 each time-step.
(3) Surveillance	(a) Universal: all settings except private residences have $\omega_j = 0.8$ (offices remain at $\omega_j = 0.6$) (b) Targeted: all settings in South West Peterborough except private residences have $\omega_j = 0.7$ (offices remain at $\omega_j = 0.6$)
(4) Economic	(a) Alter the occupation status of the people input so that unemployment is at 10% (b) Alter the occupation status of the people input so that unemployment is at 5%

The interventions described in the previous section were then incorporated by altering specific parts of the default model. One strength of the models lies in their ability allow different implementations of interventions to be tested and their (simulated) outcomes compared; this can be demonstrated by incorporating some interventions in two different ways in the models — for example surveillance being spread thinly across the whole of the geographical area, or concentrated in one specific area. The changes made to the default for each intervention tested are detailed in Table 7.1.

The models were run for 260 time-steps and the following outputs analysed:

- the mean propensity at $t = 260$,
- the maximum propensity at $t = 260$,
- and the number of people with propensity higher than 0.6 at $t = 260$.

Table 7.2 shows these outputs for the different interventions, and enables comparisons to be made between each intervention when implemented separately, and

Table 7.2: Results of crime prevention interventions

Intervention	**Mean** p **at** $t = 260$	**Max** p **at** $t = 260$	**People with** $p > 0.6$ **at** $t = 260$
No intervention	0.286	0.668	3
(1a) Early childhood: universal	0.279	0.688	5
(1b) Early childhood: targeted	0.274	0.709	3
(2) Imprisonment	0.283	0.592	0
(3a) Surveillance: universal	0.221	0.551	0
(3b) Surveillance: targeted	0.246	0.600	0
(4a) Economic: 10% unemployed	0.281	0.662	3
(4b) Economic: 5% unemployed	0.281	0.662	3
Combined	0.218	0.577	0

when all four interventions are implemented together (the "combined" intervention[2]).

These results are not intended to actually represent the relative impacts of implementing these policies, as the parameters used in the model are purely hypothetical and not based on any empirical data. However they do demonstrate the uses to which the models could potentially be put, and in particular that certain policies could have complex consequences such as (for example) successfully bringing down the mean propensity for crime across an area but not reducing the propensities of the most criminal. The results also illustrate how the models could be used to compare the impact of implementing a policy in a number of different ways, or in combination with other policies.

[2]The combined intervention is the universal early childhood intervention, imprisonment, universal surveillance, and 5% unemployment.

7.4.2 Relative Effectiveness of Radicalisation Prevention Measures

In the same way as with the criminality development model, the counter-radicalisation measures explored in the previous section can be incorporated into the computer simulation and the results compared with the default. For these tests the default version of the radicalisation model is as follows:

- **People input:** 500 people spread evenly across the geographical area, with self-control and SPI normally distributed as previously, and with socio-demographic attributes evenly distributed. One individual has been made particularly cognitively vulnerable with very high SPI and low self-control.
- **Settings input:** Identical to the criminality development model above.
- **Emergence transition:** Thresholds of $\varepsilon = 0.1$ and $\tau_1 = 1$ hour were used, with the collective efficacy coefficients raised to the power of $\phi = 0.5$.
- **Exposure transition:** The negative binomial exposure transition was used, with $\beta_0 = -6.91$, $\beta_1 = 0.9$, $\beta_2 = -0.45$, $\beta_{12} = 0.05$, and $\beta_3 = 0.028$.

As with the interventions to prevent the development of criminality, the counter-radicalisation measures discussed in the previous section can be incorporated into the simulation in a number of different guises. The specific changes made to the default radicalisation model to recreate these counter-radicalisation initiatives are shown in Table 7.3. The simulations were then run for 260 time-steps and the following outputs analysed:

- the mean propensity at $t = 260$,
- the maximum propensity at $t = 260$,
- and the number of people who are radicalised (i.e. with propensity higher than 0.1228) at $t = 260$.

These results are shown in Table 7.4 for each intervention implemented separately and the combination of all together.

Table 7.3: Counter-radicalisation measures (numbering is continued from the criminality prevention measures to facilitate later analysis)

Intervention	Changes to the default
(5) Counter-narrative - universal	For settings with radicalisation level > 0.8, multiply the attractiveness factor W by 0.75. All people have SPI reduced by 0.1.
(6) Counter-narrative - targeted event	At time $t = 100$, children at Nene Park Academy have their SPI reduced by 0.5. For these people only from $t = 100$ onwards, for settings with radicalisation level > 0.6 multiply the attractiveness factor W by 0.6.
(7) Youth group	PARCA Drop-In youth club is given a collective efficacy coefficient of 0.6, and for this setting W is multiplied by 1.2 for all people. Individuals spending more than 2 hours at PARCA Drop-In have their SPI reduced by 0.001 each time-step.
(8) Channel intervention	For individuals with propensity > 0.8, for 26 time-steps their SPI reduces by 0.001 each time-step. During this period for settings with radicalisation level > 0.6, W is multiplied by 0.75.

As before, the results in Table 7.4 are not intended to be accurate or to provide policy guidance; they are meant as an illustration as to what use the models could be put if they were correctly parameterised following a period of data collection. For example if accurate results for the two different counter-narrative interventions could be produced these simulation outputs could be used to provide an indication as to how large a targeted intervention might have to be to have a significant impact on disrupting radicalisation. A second example would be to demonstrate how much more effective interventions might be if they are implemented in co-ordination with other interventions.

7.4.3 Effects of Crime Interventions on Radicalisation, and Vice Versa

The models also allow for experiments to be carried out exploring the impact that interventions designed to prevent crime might have on radicalisation, and vice versa.

Table 7.4: Results of counter-radicalisation interventions

Intervention	**Mean** p **at** $t = 260$	**Max** p **at** $t = 260$	**No. radicalised at** $t = 260$
No intervention	0.0169	0.9491	6
(5) Counter-narrative — universal	0.0121	0.8724	5
(6) Counter-narrative — targeted	0.0136	0.9048	5
(7) Youth group	0.0153	0.9290	6
(8) Channel intervention	0.0130	0.8184	5
Combination	0.0016	0.0318	0

For example Table 7.5 shows the results when crime prevention interventions (1) to (4) are implemented in the radicalisation model. Equivalent results when counter-radicalisation measures (5) to (8) are applied to the criminality development model are shown in Table 7.6.

As with before, it must be emphasised that no useable policy conclusions can be drawn from these theoretical models. However it is encouraging to observe that the models suggest the overall most effective intervention on all three counts for the radicalisation model is the counter-radicalisation combination. Similarly for the criminality development model the crime prevention combination is the most successful intervention overall. This provides some sense that the results produced by the models are credible despite them being highly theoretical, and that with sufficient data they could be refined into tools that might serve a useful practical purpose.

7.5 Summary

This chapter started with an overview of the UK Government policy on counter-radicalisation and explored a number of specific interventions, followed by a simi-

Table 7.5: Impact of crime prevention interventions on radicalisation

Intervention	**Mean** p **at** $t = 260$	**Max** p **at** $t = 260$	**No. radicalised at** $t = 260$
(1a) Early childhood: universal	0.0156	0.9417	6
(1b) Early childhood: targeted	0.0165	0.9460	6
(2) Imprisonment	0.0067	0.3824	2
(3a) Surveillance: universal	0.0159	0.9420	7
(3b) Surveillance: targeted	0.0110	0.7823	5
(4a) Economic: 10% unemployed	0.0137	0.9155	6
(4b) Economic: 5% unemployed	0.0156	0.9575	7
Combination	0.0105	0.8417	4

lar analysis of interventions used to prevent the development of criminal propensity. Ways to incorporate these interventions into the computer simulations were then considered, before the simulations were run with the interventions incorporated, to investigate whether they had any effect on preventing criminality or radicalisation among the simulated people. A comparison of the effectiveness of different interventions was then undertaken using the models.

The final chapter will examine the impact of these findings, and those from the previous chapters, and consider further applications for the research.

Table 7.6: Impact of counter-radicalisation interventions on criminality

Intervention	**Mean** p **at** $t = 260$	**Max** p **at** $t = 260$	**People with** $p > 0.6$ **at** $t = 260$
(5) Counter-narrative — universal	0.274	0.642	2
(6) Counter-narrative — targeted	0.286	0.669	3
(7) Youth group	0.280	0.629	3
(8) Channel intervention	0.284	0.657	3
Combination	0.269	0.601	1

Chapter 8

Discussion and Conclusions

This chapter reviews the research detailed in the previous chapters, in particular considering whether the research question has been answered successfully, whether the research design was fit for purpose, and what the limitations of the research are. Applications for the research and alternative fields to which it could be applied are also considered.

8.1 The Research Question

The primary research question presented at the end of Chapter 2 which this thesis intended to answer was: are the radicalisation process and the process by which people develop the propensity to commit crime indistinguishable? This was answered by collating the findings of a number of different pieces of empirical research that had been conducted on different aspects of the criminality development process, using this to build a model replicating the process, identifying areas where radicalisation is different from criminality development, adapting the criminality development model into a model describing radicalisation, and finally running simulations of both processes to explore their similarities and differences.

An initial attempt to answer the research question came at the end of Chapter 6, where the two models were compared both in terms of their descriptions and in terms of the outputs from the simulations. However radicalisation is a far more rare occurrence in normal UK society than the process by which people develop the propensity to commit crime, meaning that unless the simulation is run with very large numbers of people (which would take a very long time, thereby causing the model to become unworkable) it was not likely that the process of radicalisation would ever happen, making it impossible to draw a comparison. In order to make the comparison the environment for the radicalisation model was changed so that it replicated a location lacking any social cohesion, as it is locations such as these (for example in conflict zones) where radicalisation is more likely to occur.

When the radicalisation simulation was run on such an environment it was found that the people who became radicalised were not the same as the people who developed the highest propensity for normal crime in the criminality development model. It was also found that the distribution of propensities for crime and radicalisation at the end of the simulation was very different, with the distribution of propensities for normal crime being approximately normally distributed and the distribution of propensities for terrorism being highly skewed. While it is difficult to obtain accurate empirical data on the numbers of people in society who have the propensity for crime or who have become radicalised, this result is consistent with what has been observed in the real world, as terrorism when it occurs is very rare, but many of those with the propensity to carry it out would have almost no limit as to what they might be prepared to do. This result is also consistent with that observed in the real world as regards *who* commits terrorist offences, as while some convicted terrorists have histories of ciminal activity, many do not.

In Chapter 7 interventions were explored and incorporated into the simulations. It was found that interventions specifically aimed at countering radicalisation were more effective against the radicalisation process than interventions targeted at reducing more general criminality, and vice versa. This lent further support to the argument already suggested by the models in Chapter 6 that, despite both processes being well described by the IVEE framework, there are fundamental differences between them, and interventions should be targeted accordingly.

In summary, through using simulation modelling of the two processes we have successfully answered the research question. The two processes follow the same theoretical framework, but there are differences in the relative importance of some causal factors within that framework, and this leads to differences in the behaviour of the processes which is sufficiently significant that interventions are more effective when they are deliberately designed to target one or other of the processes.

8.2 Key Findings

Aside from answering the research question, the simulation models developed in this thesis have also produced a number of interesting results which are worth highlighting.

The first of these is that while the interventions implemented in Chapter 7 showed that counter-radicalisation interventions were more effective at reducing radicalisation than at reducing people's propensities to commit crime (and vice versa), they also showed that in some cases there was a diffusion of benefits effect, as many of the interventions tested had a positive impact on both criminal and terrorist propensity — although some did not. It must be reiterated once again that these models are too theoretical to provide guidance on the impact of interventions, but it is clear that if the models *were* correctly calibrated and the interventions more realistically implemented, that these simulations would be capable of demonstrating whether a diffusion of benefits effect existed. They can also be used to test the effects of different implementations or "dosages" of an intervention, as some interventions were modelled both as "universal" (affecting all agents weakly) or "targeted" (affecting a sub-section of the population more strongly). The models are also flexible enough to use a variety of different metrics for measuring the effects of interventions.

A second finding worth noting is that the propensities of the individuals in the criminality development model remained quite stable relative to each other, even when substantial changes were made to the exposure transition. The impact of introducing thresholds in the transitions was also significant in reducing the propensities of the individuals, and also in causing the criminogenity levels of the settings to vary — thus making each individual's activity field and their level of exposure to criminalising moral contexts more important in determining their propensity. This highlights the importance of ensuring that future models are correctly calibrated, and suggests that further research on the length of time people need to spend in criminogenic settings in order to be influenced by them is needed.

The third key finding worth highlighting is that the radicalisation model was capable of producing very interesting patterns of propensities. In particular, when experiments were conducted to examine the effect of changing the value of parameter β_3, the resulting graphs at Figure 6.1 showed examples where an initially large amount of radicalisation diminished over time. While not explicitly one of the stylised facts against which the model was validated, the capacity of the model to produce diminishing levels of radicalisation in a population is important, as such situations do occur in the real world.

The final finding of particular interest is the differences between the distributions of propensity for crime and propensity for terrorism across the population produced by the two models when answering the research question in Section 6.3. The two different models were able to produce realistic and very different distributions of propensity: the distribution for the criminality development model was close to normal, and the distribution for the radicalisation model was more skewed, and had a far smaller mean and variance (with a couple of outliers representing radicals). Also of note was the fact that the individuals with the highest propensity for crime were not the same as those with the highest propensity for terrorism. This shows that if there were sufficient data to calibrate the models correctly, the models hold a great deal of promise in being capable of producing realistic results.

8.3 Suitability of Modelling as a Technique

We have seen that the research question was successfully answered using the intended methodology, but the question still remains as to whether the decision to use modelling as the main tool in this research project was the right one. Here we consider the way the models were developed, analysed, and validated in the course of the project, and review whether these techniques were effective.

8.3.1 Model Development

The methodology used to answer the research question relied heavily on the assumption that developing models replicating the criminality development and radicalisation processes was feasible, and in particular that the models would be of a low enough level of abstraction to allow the differences between the two processes to be identified.

The first stage of model development used empirical research previously conducted by social science researchers which was synthesised using the IVEE framework. The IVEE framework was then re-structured in the form of a Petri net in order to describe it in a procedural way, thereby allowing the model to be coded as a computer simulation. Up to this point, the criminality development and radicalisation processes appeared identical, as both could be modelled using the same IVEE framework and Petri net.

The distinguishing features of the two separate processes only became apparent when the models were parameterised. For the criminality development model this was carried out using data collected from previous empirical studies. For the radicalisation model there was insufficient data available for the parameters to be estimated accurately, however common-sense logical assumptions regarding the prevalence of radicalisation in society dictated that certain parameters needed to be altered from the values they held in the criminality development model. Suitable values for the parameters in the radicalisation model were then established via a trial-and-error approach, using the outputs from the simulation as a guide to ensure that radicalisation happened with a realistic frequency. While this method would be inadequate for constructing models intended to predict the spread of radicalisation, for models that merely seek to identify the similarities and differences between two processes this approach was sufficient.

This flexible approach to model development came about as a consequence of the nature of the research question combined with the lack of data surrounding the radicalisation process. This demonstrates that even where information is severely lacking, developing models can still be a useful exercise and provide insight into complex areas of social science. Not only that, but without developing the models to the extent that specific values for the parameters were needed, the differences between the two processes would not have been clarified. Additionally, the models developed in this thesis point the direction that further sociological research could take, and open up the possibility that such models could have operational utility in the future. Overall therefore it is concluded that the model development part of the research design was adequately suited to answering the research question.

8.3.2 Model Analysis

Following the development of the models the research design also involved a considerable amount of model analysis. This analysis took several different forms and served a number of purposes.

The first stage of analysing the models consisted of stress-testing the criminality development model, by altering the inputs and the values of the parameters to ascertain the effect that this had on the model's outputs. The outputs used for these comparisons varied according to the parameter or input being altered; for instance where changes were made to how activity fields were calculated the outputs of interest were the activity fields themselves, while for changes made to the parameters in the emergence or exposure transitions the outputs of interest were the propensities of the people in the model at the end of the simulation and the criminogenity levels of the settings. The analysis conducted at this stage mostly consisted of a visual comparison of the output graphs, as only a general overview of the impact of changing the inputs and parameters was required.

The second stage concerned the analysis of the radicalisation model. As discussed above, realistic parameters for the radicalisation model needed to be ascertained based on the way the model behaved. In order to do this, the model outputs were analysed in a very similar way to the analysis done for the criminality development model, with the specific outputs of interest being the number of people radicalised at the end of the simulation and people's propensities for terrorism. This analysis took the form of a visual comparison of output graphs showing how average propensity changes over time, and a quantitative comparison of the number of people radicalised for different parameter values. While for the criminality development model the purpose of the analysis was to check how robust the model was, for the radicalisation model the analysis informed what the definition of the model should actually be.

The purpose of the third stage of analysis was to answer the research question. This stage of analysis consisted of a comparison of both the outputs and descriptions of the two models. The analysis of the descriptions was a direct comparison of the values held by the parameters and any other changes made to the transitions. The differences between the outputs of the models were then analysed by comparing the distribution of propensities using a histogram, and by comparing each individual's propensities at the end of both simulations. This analysis allowed conclusions to be drawn regarding the similarities of the two processes.

A final stage of analysis was another comparison of the behaviours of the two processes, but this time using alternative versions of the models where a number of interventions had been incorporated. For this analysis the metrics used were the mean average propensity level of all people in the model, the maximum propensity of all people in the model, and the number of people in the model with a propensity higher than a certain level. This range of metrics allowed the differences between the impact of interventions to be observed in cases where one intervention reduces the propensity of all people by a small amount while another reduces the propensity of only the most criminally-minded or radical by a large amount.

The analysis methods used in this research were not complicated and there was no requirement for any statistical hypothesis testing. The reason for this is that the models were not intended to have a high degree of accuracy, and so there was no need for any quantitative goodness-of-fit tests. Additionally the models developed are deterministic models, so when a parameter is altered and the outputs change it can immediately be concluded that the change occurred as a direct result of altering that parameter. The usual null hypothesis in a statistical test — that changing a parameter has no effect — would therefore always be rejected if any difference (no matter how small) were observed. Thus a simple comparison was sufficient. It is concluded that the methods used to analyse the models were appropriate and effective at answering the research question.

8.3.3 Model Validation

The method used to validate the models was to compare the outputs from the simulations with a list of "stylised facts", to see whether these were reproduced by the models. A list of five stylised facts was compiled separately for the criminality development model and the radicalisation model; these stylised facts were relatively broad and concerned basic features of criminality and radicalisation in the real word that the models needed to be able to replicate, such as the capacity for propensity to go down as well as up, and for individual agents to all have different propensities. The model outputs were largely found to replicate these phenomena (with some caveats), and thus it was concluded that the models were sufficiently validated and realistic to be used to answer the research question.

As has been discussed extensively at several points in this thesis, in an ideal world there would be sufficient data available to both calibrate the models accurately and then to validate them using statistical methods. However in the absence of such data, alternative methods must be explored and the question asked as to whether these methods are adequate. In the case of the models in this thesis, it was acknowledged from the start that they would be theoretical models whose primary purpose was to further understanding of the criminality development and radicalisation processes and the differences between them, rather than being operational models to be used for prediction. The level of validation required for the models to be able to fulfil their purpose was therefore low. However validation was still a very necessary part of the overall research process; with no validation process at all, the models could have produced highly unrealistic results and their use could have resulted in conclusions that might have been very misleading. As it is, the validation process followed in this thesis showed that the outputs for both models were largely realistic in terms of the levels of individual propensities, distribution of propensities across the populations, and the state of the systems overall. The stylised facts for the two systems were very similar, but sufficiently different from each other for distinctions to be made between them — and indeed the outputs from the two models were shown to be different from each other in the way required by the stylised facts.

However the method of validation by stylised facts is not perfect. Its greatest failing is that it is highly dependent on the list of stylised facts used, and unless a list has previously been agreed upon by multiple experts in the field it is highly subjective: I may consider a phenomenon to be a fundamental characteristic of criminal propensity, but your opinion may differ. The question therefore remains as to whether the list of stylised facts used in this thesis is rigorous enough and has sufficiently granularity for the models to have been adequately validated. However here again we return to the problem that not much data exists in the field of research into criminal and terrorist propensities, making it difficult to generate stylised facts; ultimately further traditional social scientific research is needed for such stylised facts to be generated, and thus for more rigorous model validation to be possible.

8.4 Assumptions and Limitations of the Research

Modelling by its very nature involves simplifying reality, and therefore a number of assumptions had to be made throughout this thesis about the real world systems that were being modelled. The first and most fundamental of these was to use the IVEE framework as the basis of the computer simulations. A key piece of further research would therefore be to create a computer simulation of propensity development with a different theoretical framework underlying the models, and then to see if similar results were achieved. This would also enable the sufficiency of IVEE when compared with other possible theoretical frameworks to be tested, by comparing the number of stylised facts that simulations based on the different frameworks were able to replicate. The assumption was also made throughout that well-established theories in criminological research such as routine activity theory, rational choice theory and situational action theory are correct.

Within the IVEE framework several further assumptions were made in order to make it possible to create a computer simulation of the process. The first of these concerned the way the factors associated with cognitive susceptibility were measured and modelled. The negative binomial equation used in the exposure transition of the model was taken directly from an empirical study into how self-control, susceptibility to peer influence, and peer delinquency affect the probability that an individual will commit an act of delinquency over the subsequent 12 month period. An assumption therefore had to be made that susceptibility to peer influence could be treated as a proxy for an individual's morality, and peer delinquency as a proxy for exposure to criminogenic influences. The former assumption was supported by additional academic studies, but the latter was not, meaning that it is possible that the assumed parity between peer delinquency and exposure to criminogenic influences may not actually hold. Additionally, the equation in the exposure transition came from a single study; further studies would need to be done to replicate the results before this equation can be used with a high degree of confidence.

A further assumption within the IVEE framework was to use the retail model developed by Harris and Wilson (1978) as the basis for modelling individuals' activity fields. One obvious difference between the flow of money that was being modelled by Harris and Wilson and the flow of people in the modelling of activity fields is that retail activity is discretionary, whereas going to school or to a workplace is obligatory. This was managed in the model by categorising the settings and using different rules for workplaces and educational establishments, however the validity of the assumption has not been proven and alternative methods for modelling how people move around may generate better results. An alternative, for example, might be to use research conducted by González et al. (2008) among others into how people move around space, and to use this to create activity spaces for individuals in a similar way to that done in some environmental criminological models.

A final unknown in terms of the modelling process is the degree to which the geographical setting is important in the generation of a plausible set of emerging features. This forms a key tenet in IVEE, as the exposure to and emergence of radicalising settings is something which happens in a particular environment. In order to replicate this the model was located in a representation of an average UK city. However the actual importance of geography in the model remains an unanswered question; if the model were located in a completely different environment, or perhaps a much simpler, theoretical environment, would the models have produced the same results and been able to answer the research question?

Aside from the limitations associated with the assumptions made during the modelling process, the research is also subject to a number of additional limitations, the most significant of which has been the lack of data available with which to parameterise and validate the models. This lack of data was particularly stark for the radicalisation model, but even for the criminality development model there was insufficient data to allow the emergence of radicalising settings or people's activity fields to be modelled with much accuracy. While it is assessed that the amount of data available was sufficient for the purposes of answering the research question, the secondary aim of the project — to construct models that could potentially predict the spread of criminality or radicalisation and be of practical use to practitioners — was completely infeasible.

This project was also limited by a lack of computer processing capacity. In particular this affected the analysis of the behaviour of the radicalisation model. Radicalisation is rare, so in order for it to emerge organically in the computer simulation there would need to be over 100,000 people input to the model, and this was significantly greater than the computer was able to process. For this reason a short-cut was taken, which was to force one of the 500 people to be highly cognitively susceptible to ensure that the radicalisation process started, and an assumption was made that the results from the 500 people model could be scaled up to larger population sizes. However it is possible that this assumption is incorrect, and that the model would behave differently for larger numbers of people.

Finally, an additional limitation lies in the lack of sophistication of some aspects of the model, which may have been modelled too simply. The aspects in question tally with the parts of the process for which there is not much data — namely the generation of activity fields and the emergence of criminogenic or radicalising settings. For example, the collective efficacy coefficient has been modelled as a single number, but it may be better modelled as a vector with different dimensions representing, say, the level of community cohesion or the amount of surveillance. This would allow each dimension to have a different impact on the emergence of criminogenic or radicalising settings, and would make it possible to model interventions such as increased surveillance more realistically. However, with so little known about the mechanisms by which such settings emerge, a lower level of abstraction was not possible. Likewise individual preferences for finding some settings more attractive than others were modelled very simply via the similarity function; this could easily be made into a more sophisticated model of rational choice, for example through using a “preference function” such as that devised by Gintis and Helbing (2015). But without further information about which factors really are important, a more sophisticated function could not be used.

These limitations could however all be overcome in the future after further sociological research on the criminality development and radicalisation processes has been carried out, and by using a more powerful computer processor.

8.5 Applications for the Research

8.5.1 Operationalising the Models

As has been said many times throughout this thesis, the models that have been developed are largely theoretical and should not be used for prediction or to provide policy guidance in their current state. However there is scope for them to be used this way in the future if sufficient empirical data is available for the models to be parameterised and the results validated. If this were done, there are a number of uses to which the models could be put. These include:

- Identifying which settings or wider geographical areas have the most criminogenic / radicalising influence, in order to help practitioners target their interventions on particular areas.
- Identifying the socio-demographic characteristics of those most likely to develop the propensity for crime or terrorism, again to help target interventions.
- Testing which interventions or combinations of interventions are likely to be most effective and whether any have unintended negative consequences.
- Exploring the idea of a "tipping point": what would have to change for radicalisation or criminality to become pervasive and what indicators might suggest that the tipping point was being approached?
- Scenario generation, such as:
  - Changing the socio-demographic make up of an area over time to see how this alters the effectiveness of interventions;
  - Giving one setting a very high collective efficacy coefficient then testing what measures can be used to deter people from going there and what overall impact such measures would have;
  - Exploring the impact of a small number of individuals with a very high propensity for crime or terrorism on those around them.

Although these applications would only be possible with more realistically parameterised versions of the models, there is one additional application for the models in their current form, and that is to use them as a guide to social scientists in the fields of criminology and counter-radicalisation as to where the key knowledge gaps in their fields are, in the hopes that this will direct their future research. In particular, there are clear knowledge gaps in both processes as regards selection mechanisms — that is, what factors lead a person to go to one setting over another, and how important those factors are. There are also gaps concerning the mechanism by which collective efficacy makes a setting more or less criminogenic or radicalising. Finally, for the radicalisation process a knowledge gap exists concerning the precise relationship between cognitive factors (self-control and morality), exposure to radicalising influences, and the extent to which a person's propensity for terrorism changes. For each of these areas the basic theory of what the causal mechanisms are has been developed, but the relationships have never been quantified — and until they are, these models will not be accurate enough to put into operational use.

8.5.2 Alternative Fields

Aside from the social processes that these models were intended to replicate, the basic structure of the models could also be applicable to a number of alternative fields. While the IVEE theoretical framework underpinning the models was developed with radicalisation in mind, it is essentially simply a way to synthesise three different levels — individual, ecological and systemic — underlying a complex social process, and thus could be transferrable to other processes that operate on these three levels. And any process to which the IVEE framework can be applied could be modelled in a similar way to the criminality development and radicalisation processes in this thesis.

The more obvious candidates for alternative fields to which the models in this thesis might be applicable are other processes describing human behaviour. An example not too dissimilar to the original criminality development model is the spread of users of illegal drugs. This is clearly the outcome of a process working at the individual, ecological and systemic levels, as the individual's own cognitive decision-making attributes affect whether they decide to take drugs, in addition to the prevalence of drugs and drug users at the settings the person visits on a day-to-day basis. A very similar argument can be made for the process by which an individual decides to start or stop smoking, showing that the models could be modified to assist practitioners in the field of public health in addition to security and crime. Consumer behaviour is another process which operates at multiple levels and is one where the settings that a person visits affect the decisions they make, making market research another alternative field to which the models could be applied. For these latter processes there is no requirement for an individual's morality to change, and further research would have to be carried out to determine what functions would be most suitable for the exposure and emergence transitions within the models, but the basic structure of the Petri net would be identical to that used for the criminality development and radicalisation models.

With some subtle changes to this basic Petri net structure the models could be made applicable to a range of other subjects. For instance, instead of the two states representing people and settings, they could represent investors and publicly traded companies to create a model replicating the stock market. The amount of exposure an investor has to certain companies would affect their decisions over where next to invest, making the exposure transition still applicable, while where they choose to invest would influence certain attributes of the companies (such as share price), making the emergence transition applicable. While clearly a simplification (as of course all models are), further complexity could easily be added by increasing the number of different states and transitions in the model.

8.6 Conclusion

This research project has revolved around the use of mathematical modelling as a tool to answer hard questions in social science. The areas chosen to be the focus of this research — criminality and radicalisation — were deliberately chosen because they are difficult areas in which to carry out conventional social science research. Measuring someone's propensity to commit crime or terrorism is difficult to do accurately, and on a large scale is extremely resource-intensive, making empirical data hard to come by. It was for this reason that it was hoped that modelling might be able to make a positive contribution to the field, although as the models themselves also rely on the availability of data their utility is unfortunately limited.

Now was the right time for a research project like this to take place. The IVEE framework provided the foundation on which the models could be built, and without it there would have been no starting point. Further, without previous studies quantifying the relationships between psychological attributes, exposure to external criminogenic influences and the probability of future criminal activity there would have been insufficient data for even the most simple parameterisation to happen. Clearly further data would lead to better models, but the minimum requirement for data was satisfied, and this project has demonstrated that even these simple theoretical models can serve a purpose. As a result of this research we have learned that the process by which people develop the propensity to commit crime is different from the process of radicalisation, and that interventions should be targeted accordingly. Further, we have identified key knowledge gaps in the field and hope that this will direct further social science research. Finally, the models developed are an important first step towards creating operational simulations that would allow policy-makers and practitioners to test the impact of interventions before they are implemented. The basic structure of the work is done: it simply remains for the blanks to be filled in.

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Appendices

Appendix A

Full Model Description

A.1 Criminal Propensity Development Model

A.1.1 Overview

The model is an individual-level state transition model comprising four states and two transitions. The four states are:

- Neutral person
- Neutral setting
- Criminally-minded person
- Criminogenic setting

The model can also be described as an agent-based model, as these four states group naturally into two types of agent: a "Person" agent and a "Setting" agent, each of which have a number of different attributes that are explained in more detail below.

The two transitions are:

- Exposure: this has a neutral person and a criminogenic setting as inputs, and a criminally-minded person and criminogenic setting as outputs.

- Emergence: this has a criminally-minded person and a neutral setting as inputs, and a criminally-minded person and a criminogenic setting as outputs.

The arrangements of the states and transitions can be depicted as a Petri Net, as in Figure A.1.

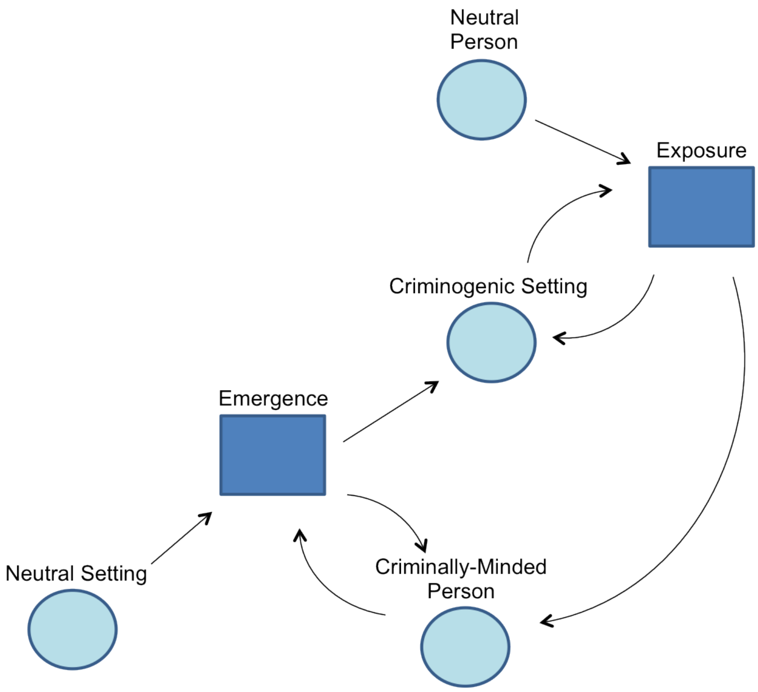

Figure A.1: IVEE Petri net for criminality development

A.1.2 The Person Agent

In the descriptions that follow, i refers to a person, j refers to a setting, and k refers to a setting type.

The Person agent has the following attributes:

- Propensity, p_i: this is a real number whose bounds depend on the function used in the exposure transition; for the negative binomial version of the model p_i lies between 0 and 1. The higher the number, the greater the person's propensity for criminal behaviours. Propensity changes after the exposure transition is called.

- Susceptibility to Peer Influence (SPI), x_1. This is an unbounded real number.

The higher the number, the more susceptible the person is to criminogenic influences. SPI reduces between the ages of 14 and 18, but is otherwise static. It is used to calculate propensity, and also as part of the similarity function S_{ij} (which models homophily, so settings are more attractive if the people who go there are similar).

- Self-Control, x_2: this is constant for each person, and can take any real value. The higher the number, the more self-control the person has. It is used to calculate propensity and as part of the similarity function S_{ij}.
- Activity Field, f_{ijk}: this is a table consisting of the percentage of time the person is expected to spend in each setting every week. The way it is calculated is explained below.
- Pattern of Life, Q_{ik}: this is a vector comprising values for each type of setting, and is determined by a person's age, religion, and occupation. It is used when generating the person's activity field, and is explained in more detail below.
- Home Location: these are (x, y) co-ordinates for where the person lives, and is constant for each person. This is used to calculate c_{ij}, the distance between the person's home and the settings, which is used to generate the person's activity field.
- Age: used in the calculation of the pattern of life Q_{ik}, the similarity function S_{ij}, and for reducing the value of i's SPI while i is between the ages of 14 and 18.
- Religion: used when calculating pattern of life Q_{ik} and the similarity function S_{ij}. It is one of Christian, Muslim, or None.
- Occupation: used when calculating pattern of life Q_{ik}. It is one of Employed, Student, or Unemployed.

A.1.3 The Setting Agent

The Setting agent has the following attributes:

- Name
- Criminogenity Level, c_j: this is a number whose bounds are linked to the exposure transition; for the negative binomial version of the model it is always greater than or equal to zero. The higher the number, the more criminogenic the setting is. Criminogenity changes after the emergence transition is called.
- Size, $|j|$: this is an integer representing the size of a setting, either in terms of the number of people to visit the setting, or in terms of area[1]. It is used when calculating the attractiveness of a setting to a person (described below).
- Collective Efficacy Coefficient, ω_j: this is a positive number. The higher the number, the lower the collective efficacy of a setting. The collective efficacy coefficient is static for each setting.
- Location: these are (x, y) co-ordinates for the geographical location of the setting. It is used in conjunction with the person's home location when generating activity fields.
- Type, k: this categorises settings as workplaces, religious centres, social centres and residences. It is used when calculating a person's pattern of life. The setting types are as follows:
  - Workplaces: Office, University, School
  - Religious Centres: Church, Mosque
  - Social Centres: High Street, Youth Club, Leisure Centre
  - Residences: Own, Friend

A.1.4 Activity Field Generation

The person agent's activity field is a table showing the percentage of time person i spends in setting j of type k for each timestep t, as follows:

[1]The way a setting's size is measured must be consistent for settings of the same type.

Setting type	a	a	...	k
Setting	1	2	...	j
Time spent (%)	$f_{i1a}(t)$	$f_{i2a}(t)$	...	$f_{ijk}(t)$

We define

$$f_{ijk}(t) = A_{ik}(t)Q_{ik}(t)W_{ij}(t)^{\alpha}e^{-\beta c_{ij}}$$

where

$$A_{ik}(t) = \frac{1}{\sum_{l\in J_k} W_{il}(t)^{\alpha}e^{-\beta c_{il}}}$$

is the scaling factor; the set J_k in the summation is the set comprising all settings of type $k \in K$ where K is such that the family $\{J_k\}_{k\in K}$ is a partition of J. This scaling factor ensures that $\sum_{j\in J_k} f_{ijk}(t) = Q_{ik}(t)$.

$Q_{ik}(t)$ is the person's pattern of life, dependent on their selection quotient (see below).

c_{ij} is the distance as the crow flies between person i's home and setting j.

$W_{ij}(t)$ is the attractiveness of setting j to person i, and is a function of the setting's size $|j|$ and the similarity function $S_{ij}(t)$.

The similarity function $S_{ij}(t)$ is a measure of how similar person i is to the other people who visit setting j. It is defined as $S_{ij}(t) = 1 - D_{ij}(t)$, where $D_{ij}(t)$ is the difference function:

$$D_{ij}(t) = \frac{1}{5}\left(\eta_1 Drel_{ij}(t) + \eta_2 Dp_{ij}(t) + \eta_3 Dsc_{ij}(t) + \eta_4 Dspi_{ij}(t) + \eta_5 Dage_{ij}(t)\right)$$

where the η values enable different weighting to be given to each attribute. For the default version of the model these are set to 1, so that all attributes have the same weight.

The difference functions for the five attributes are defined as:

Religion:

$$Drel_{ij}(t) = \left| rel_i(t-1) - \sum_{\substack{\forall i \text{ s. t.} \\ f_{ijk}(t-1)>0}} \frac{rel_i(t-1)}{n} \right|$$

where a Christian is coded 0 and a Muslim is coded 1, and n is the number of people such that $f_{ijk}(t-1) > 0$ (i.e. the number of people visiting setting j in the previous timestep).

Propensity:

$$Dp_{ij}(t) = \left| p_i(t-1) - \sum_{\substack{\forall i \text{ s. t.} \\ f_{ijk}(t-1)>0}} \frac{p_i(t-1)}{n} \right|$$

with n defined as before.

Self-Control:

$$Dsc_{ij}(t) = 1 - e^{-|sc_i - sc_j(t-1)|}$$

where sc_i is the self-control level of i and $sc_j(t-1)$ is the mean average of sc_i for all i visiting setting j at time $t-1$.

Susceptibility to Peer Influence:

$$Dspi_{ij}(t) = 1 - e^{-|spi_i(t-1) - spi_j(t-1)|}$$

where $spi_i(t-1)$ is the SPI of i at time $t-1$ and $spi_j(t-1)$ is the mean average of spi_i for all i visiting setting j at time $t-1$.

Age:

$$Dage_{ij}(t) = \frac{1}{5} \left| age_i(t-1) - \sum_{\substack{\forall i \text{ s. t.} \\ f_{ijk}(t-1)>0}} \frac{age_i(t-1)}{n} \right|$$

where age is coded as in Table A.1.

α and β are parameters of the model.

There are two exceptions when generating activity fields:

Table A.1: Age coding scheme

Age	Code
Under 16	0
16-18	1
19-23	2
24-30	3
31-40	4
Over 40	5

- Workplaces: only the most likely workplace is included in the activity field. This is defined as the workplace that generates the largest value of $f_{ijk}(t)$ using the equation above. All other workplaces are set to zero, so a person has only one workplace during each time-step.

- Friend's residences: person *i*'s "best friend" is calculated as the person whose activity field most closely resembles that of *i*. A person will spend a proportion of their time at their best friend's house, but no other private residences during each time-step.

A.1.5 Pattern of Life Generation

The person agent has a function that defines their pattern of life. This uses attributes of person *i* such as age, religion and occupation to determine the types of setting that *i* is more or less likely to visit. It is determined via a look-up table which is at Appendix B. The values in the look-up table are calculated using the following rules:

- Person *i* is awake for 112 hours per week;

- If person *i* attends school they do so for 35 hours per week;

- If person *i* attends university or a workplace they do so for 40 hours per week;

- If person *i* has a religion they attend their place of worship for 2 hours per week;

- For person *i* under the age of 20, *i*'s remaining waking hours are equally split between their home, a friend's house, high streets, leisure centres, and youth clubs;

- For person i over the age of 20, i's remaining waking hours are equally split between their home, friend's house, high street, and leisure centre.

A.1.6 The Transitions

A.1.6.1 Emergence

The emergence transition occurs when a setting forms a significant part of a criminally-minded person's activity field — that is, for any setting j for which $f_{ijk}(t) > \tau_1$ for some time threshold τ_1, where person i has a significant propensity p for some criminal behaviour (so $p_i(t) > \varepsilon$ for some propensity threshold ε).

After the emergence transition the criminogenity of a setting j at time t is defined to be:

$$c_j(t) = \frac{\omega_j}{n} \left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t) > \tau_1 \\ \& \ p_i(t) > \varepsilon}} p_i(t) \right)$$

where $p_i(t)$ is the propensity of person i to some crime at time t, n is the number of people i such that $f_{ijk}(t) > \tau_1$, and ω_j is the collective efficacy coefficient of the setting.

A.1.6.2 Exposure

The exposure transition occurs when person i spends a non-zero amount of time in a criminogenic setting j. The exposure transition is defined to be the way the three variables of cognitive susceptibility, criminogenic influence, and criminal propensity (comprising morality and self-control) interact. The following two functions were used for the exposure transition in this thesis:

The Negative Binomial Version:

$$p_i(t) = 1 - \left(\frac{1}{1 + 0.1228e^{-0.23+0.25x_1(i,t)-0.13x_2(i)+0.15x_1(i,t)x_2(i)+0.69x_3(i,t)}} \right)^{8.14}$$

where $x_1(i,t)$ is i's susceptibility to peer influence at time t, $x_2(i)$ is i's self-control, and $x_3(i,t)$ is a measure of the amount of exposure to criminogenic settings that person i has had at time t. For the default simulation $x_3(i,t)$ was defined as the mean average of the criminogenity of each setting visited by person i that time step. x_3 is transformed into a z-score using $\mu = \mathrm{E}(p_i(t)) = 0.5314549$ and variance 0.04.

The Alternative Version:

$$p_i(t) = m_i(t) - x_2(i)$$

where person i's morality is

$$m_i(t) = x_1(i,t) + \theta x_3(i,t) e^{-\gamma x_2(i)}$$

x_1, x_2 and x_3 are as before, and θ and γ are model parameters.

A.1.7 One Time Step

One time-step in the simulation represents one week. Each time-step the simulation goes through the following steps:

1. Every 52 time-steps increase people's ages by 1. Decrease the SPI for individuals between the ages of 14 and 18.
2. Calculate each individual's activity field
3. Calculate the mean propensity of the people visiting each setting, and the mean criminogenity of the settings visited by each person
4. Call the emergence transition

5. Calculate the amount of exposure to criminogenic settings each person experiences, and transform to a z-score
6. Call the exposure transition
7. Record criminogenities and propensities in output files.

A.2 Radicalisation Model

The radicalisation model is identical to the criminality development model except that in place of “criminogenic settings” and “criminally-minded people” the agents are “radicalising settings” and “radicalised people”. The transitions are also different, as described in Chapter 6, with the final versions used in the analysis being as follows:

Exposure: After the exposure transition the propensity p of person i for terrorist activity at time t is:

$$p_i(t) = 1 - \left(\frac{1}{1 + 0.1228e^{-6.91 + 0.9x_1(i,t) - 0.45x_2(i) + 0.05x_1(i,t)x_2(i) + 0.028x_3(i,t)}} \right)^{8.14}$$

where $x_1(i,t)$, $x_2(i)$ and $x_3(i,t)$ represent person i's susceptibility to peer influence, self-control, and exposure to radicalising settings at time t respectively (as in the criminality development model).

Emergence: After the emergence transition the radicalisation level r of setting j at time t is:

$$r_j(t) = \frac{\omega_j^{0.5}}{n} \left(\sum_{\substack{\forall i \text{ s.t.} \\ f_{ijk}(t) > \tau_1 \\ \& \; p_i(t) > \varepsilon/\omega_j}} p_i(t) \right)$$

for $\tau_1 = 1$ hour and $\varepsilon = 0.1$.

Appendix B

Activity Field Generation Look-Up Table

The look-up table below shows the value of the selection quotient Q_{ik} for each type of setting k and for people with different socio-demographic characteristics. It is calculated using the following assumptions:

- Person i is awake for 112 hours per week;
- If person i attends school they do so for 35 hours per week;
- If person i attends university or a workplace they do so for 40 hours per week;
- If person i has a religion they attend their place of worship for 2 hours per week;
- For person i under the age of 20, i's remaining waking hours are equally split between their home, a friend's house, high streets, leisure centres, and youth clubs;
- For person i over the age of 20, i's remaining waking hours are equally split between their home, friend's house, high street, and leisure centre.

For the default model, each person is considered to have one main friend, and it is this person's house that they visit. Person i's best friend is defined to be the person who has the most similar activity field to i for non-residential settings.

Age(i)	**Religion(i)**	**Occupation(i)**	**Setting Type(j)**	**Q**
Under 18	Christian	Student	School	0.3125
			University	0
			Office	0
			Church	0.0179
			Mosque	0
			High Street	0.1339
			Youth Club	0.1339
			Leisure Centre	0.1339
			Home	0.1339
			Friend's Home	0.1339
Under 18	Muslim	Student	School	0.3125
			University	0
			Office	0
			Church	0
			Mosque	0.0179
			High Street	0.1339
			Youth Club	0.1339
			Leisure Centre	0.1339
			Home	0.1339
			Friend's Home	0.1339
Under 18	None	Student	School	0.3125
			University	0
			Office	0
			Church	0
			Mosque	0
			High Street	0.1375
			Youth Club	0.1375

Age(*i*)	**Religion(*i*)**	**Occupation(*i*)**	**Setting Type(*j*)**	**Q**
			Leisure Centre	0.1375
			Home	0.1375
			Friend's Home	0.1375
18-19 yrs old	Christian	Student	School	0
			University	0.357
			Office	0
			Church	0.0179
			Mosque	0
			High Street	0.125
			Youth Club	0.125
			Leisure Centre	0.125
			Home	0.125
			Friend's Home	0.125
18-19 yrs old	Muslim	Student	School	0
			University	0.357
			Office	0
			Church	0
			Mosque	0.0179
			High Street	0.125
			Youth Club	0.125
			Leisure Centre	0.125
			Home	0.125
			Friend's Home	0.125
18-19 yrs old	None	Student	School	0
			University	0.357
			Office	0
			Church	0
			Mosque	0

Age(i)	**Religion(i)**	**Occupation(i)**	**Setting Type(j)**	**Q**
			High Street	0.1286
			Youth Club	0.1286
			Leisure Centre	0.1286
			Home	0.1286
			Friend's Home	0.1286
Over 20	Christian	Student	School	0
			University	0.357
			Office	0
			Church	0.0179
			Mosque	0
			High Street	0.1563
			Youth Club	0
			Leisure Centre	0.1563
			Home	0.1563
			Friend's Home	0.1563
Over 20	Muslim	Student	School	0
			University	0.357
			Office	0
			Church	0
			Mosque	0.0179
			High Street	0.1563
			Youth Club	0
			Leisure Centre	0.1563
			Home	0.1563
			Friend's Home	0.1563
Over 20	None	Student	School	0
			University	0.357
			Office	0

Age(*i*)	Religion(*i*)	Occupation(*i*)	Setting Type(*j*)	Q
			Church	0
			Mosque	0
			High Street	0.1607
			Youth Club	0
			Leisure Centre	0.1607
			Home	0.1607
			Friend's Home	0.1607
Under 20	Christian	Employed	School	0
			University	0
			Office	0.357
			Church	0.0179
			Mosque	0
			High Street	0.125
			Youth Club	0.125
			Leisure Centre	0.125
			Home	0.125
			Friend's Home	0.125
Under 20	Muslim	Employed	School	0
			University	0
			Office	0.357
			Church	0
			Mosque	0.0179
			High Street	0.125
			Youth Club	0.125
			Leisure Centre	0.125
			Home	0.125
			Friend's Home	0.125
Under 20	None	Employed	School	0

Age(i)	**Religion(i)**	**Occupation(i)**	**Setting Type(j)**	**Q**
			University	0
			Office	0.357
			Church	0
			Mosque	0
			High Street	0.1286
			Youth Club	0.1286
			Leisure Centre	0.1286
			Home	0.1286
			Friend's Home	0.1286
Over 20	Christian	Employed	School	0
			University	0
			Office	0.357
			Church	0.0179
			Mosque	0
			High Street	0.1563
			Youth Club	0
			Leisure Centre	0.1563
			Home	0.1563
			Friend's Home	0.1563
Over 20	Muslim	Employed	School	0
			University	0
			Office	0.357
			Church	0
			Mosque	0.0179
			High Street	0.1563
			Youth Club	0
			Leisure Centre	0.1563
			Home	0.1563

Age(*i*)	Religion(*i*)	Occupation(*i*)	Setting Type(*j*)	Q
			Friend’s Home	0.1563
Over 20	None	Employed	School	0
			University	0
			Office	0.357
			Church	0
			Mosque	0
			High Street	0.1607
			Youth Club	0
			Leisure Centre	0.1607
			Home	0.1607
			Friend’s Home	0.1607
Under 20	Christian	Unemployed	School	0
			University	0
			Office	0
			Church	0.0179
			Mosque	0
			High Street	0.1964
			Youth Club	0.1964
			Leisure Centre	0.1964
			Home	0.1964
			Friend’s Home	0.1964
Under 20	Muslim	Unemployed	School	0
			University	0
			Office	0
			Church	0
			Mosque	0.0179
			High Street	0.1964
			Youth Club	0.1964

Age(i)	**Religion**(i)	**Occupation**(i)	**Setting Type**(j)	**Q**
			Leisure Centre	0.1964
			Home	0.1964
			Friend's Home	0.1964
Under 20	None	Unemployed	School	0
			University	0
			Office	0
			Church	0
			Mosque	0
			High Street	0.2
			Youth Club	0.2
			Leisure Centre	0.2
			Home	0.2
			Friend's Home	0.2
Over 20	Christian	Unemployed	School	0
			University	0
			Office	0
			Church	0.0179
			Mosque	0
			High Street	0.2456
			Youth Club	0
			Leisure Centre	0.2456
			Home	0.2456
			Friend's Home	0.2456
Over 20	Muslim	Unemployed	School	0
			University	0
			Office	0
			Church	0
			Mosque	0.0179

Age(i)	**Religion(i)**	**Occupation(i)**	**Setting Type(j)**	**Q**
			High Street	0.2456
			Youth Club	0
			Leisure Centre	0.2456
			Home	0.2456
			Friend's Home	0.2456
Over 20	None	Unemployed	School	0
			University	0
			Office	0
			Church	0
			Mosque	0
			High Street	0.25
			Youth Club	0
			Leisure Centre	0.25
			Home	0.25
			Friend's Home	0.25

Appendix C

Geographical and People Input to the Simulation

C.1 Geographical Input

The default area programmed into the model is Peterborough. The settings included in the model and their attributes are in the table below:

Name	**Size** [1]	**Location** *x*-**coord**	**Location** *y*-**coord**	**Type**
Arthur Mellows Village College	1400	14.97	105.71	School
Hampton College	750	17.79	94.39	School
Jack Hunt Trust	1466	16.91	99.25	School
Ken Stimpson Community School	1100	16.86	103.89	School
King's School	1000	19.43	99.67	School
Nene Park Academy	1200	16.6	96.63	School
Ormiston Bushfield Academy	950	15.19	95.43	School

[1] Size is measured in terms of the number of people visiting the setting, unless otherwise specified.

Name	**Size** [1]	**Location** *x*-**coord**	**Location** *y*-**coord**	**Type**
St John Fisher RC School	750	20.54	99.67	School
Stanground Academy	1450	20.34	96.03	School
Thomas Deacon Academy	2200	19.72	100.33	School
Voyager Academy	1645	17.49	102.15	School
Peterborough Regional College	15500	20.07	100.21	University
University Centre Peterborough	850	20.07	100.21	University
Perkins Engines Company Ltd	2848	16.11	103.13	Office
Indesit Company Ltd	2445	18.45	96.68	Office
British Sugar Plc	1994	18.07	97.53	Office
Vital Recruitment Ltd	1821	17.72	99.97	Office
Produce World Ltd	1341	23.6	93.56	Office
Fairline Boats Ltd	1040	4.66	88.18	Office
Diligenta Ltd	964	14.1	96.55	Office
Interecruit Ltd	850	18.82	100.34	Office
Faidhan-e-Madina	3000	18.74	99.38	Mosque
Markazi Jamia	1650	18.59	99.95	Mosque
MKSI Community Hussaini Islamic Centre	550	20.2	99.01	Mosque
Masjid Khadijah Islamic Centre	500	18.8	99.82	Mosque
Dar-as-Salaam	500	19.06	100.26	Mosque
Al-Mustafa International	100	18.72	100.31	Mosque

Name	**Size** [1]	**Location** x**-coord**	**Location** y**-coord**	**Type**
Qasimani	100	18.71	99.78	Mosque
Peterborough Cathedral	500	19.26	98.71	Church
Kingsgate Community	1400	21.89	100.95	Church
Peterborough International Christian Centre	150	18.63	100.58	Church
Oundle Road Baptist Church	150	18.87	97.89	Church
Westgate Church	150	18.98	99	Church
Pentecostal Church	150	18.31	99.22	Church
St Andrew's URC Church	150	17.04	99.39	Church
St Mary's Church	150	19.63	99.04	Church
Werrington Centre	4204 m^2	17.08	104.12	High Street
Millfield Centre	8040 m^2	18.91	100.25	High Street
Bretton Centre	13425 m^2	16.31	100.51	High Street
Orton Centre	17418 m^2	15.25	95.31	High Street
Serpentine Green Shopping Centre	25687 m^2	17.9	95.08	High Street
Queensgate Centre	81000 m^2	18.97	98.79	High Street
Hampton Leisure Centre	10000	17.99	94.51	Leisure Centre
Vivacity Premier Fitness	10000	18.26	95.05	Leisure Centre
Werrington Leisure Centre	10000	16.86	103.89	Leisure Centre
Bushfield Leisure Centre	10000	15.19	95.43	Leisure Centre
Regional Fitness Centre	10000	19.9	98.56	Leisure Centre
Big Up Youth Club	100	18.85	99.46	Youth Club
Eye Youth Club	100	22.86	103.17	Youth Club

Name	**Size** [1]	**Location** *x*-**coord**	**Location** *y*-**coord**	**Type**
PARCA Drop-In	100	18.73	100.61	Youth Club
Spinney Youth Club	100	16.73	100.4	Youth Club
PYA Youth Club	100	18.41	100.21	Youth Club
Welland Youth Club	100	20.9	101.42	Youth Club
Wittering Drop-In	100	5.94	102.36	Youth Club
Werrington Church Youth Club	100	16.96	103.16	Youth Club
Person i's Home	4	xCoord(i)	yCoord(i)	Residence

The location of these settings on a map of Peterborough is displayed in Figure C.1.

C.2 People Input

The attributes of the people input to the simulation are evenly distributed, as are the geographical locations of their homes. The locations of each person's home is displayed in Figure C.2, and the number of people with each attribute is shown in Table C.2.

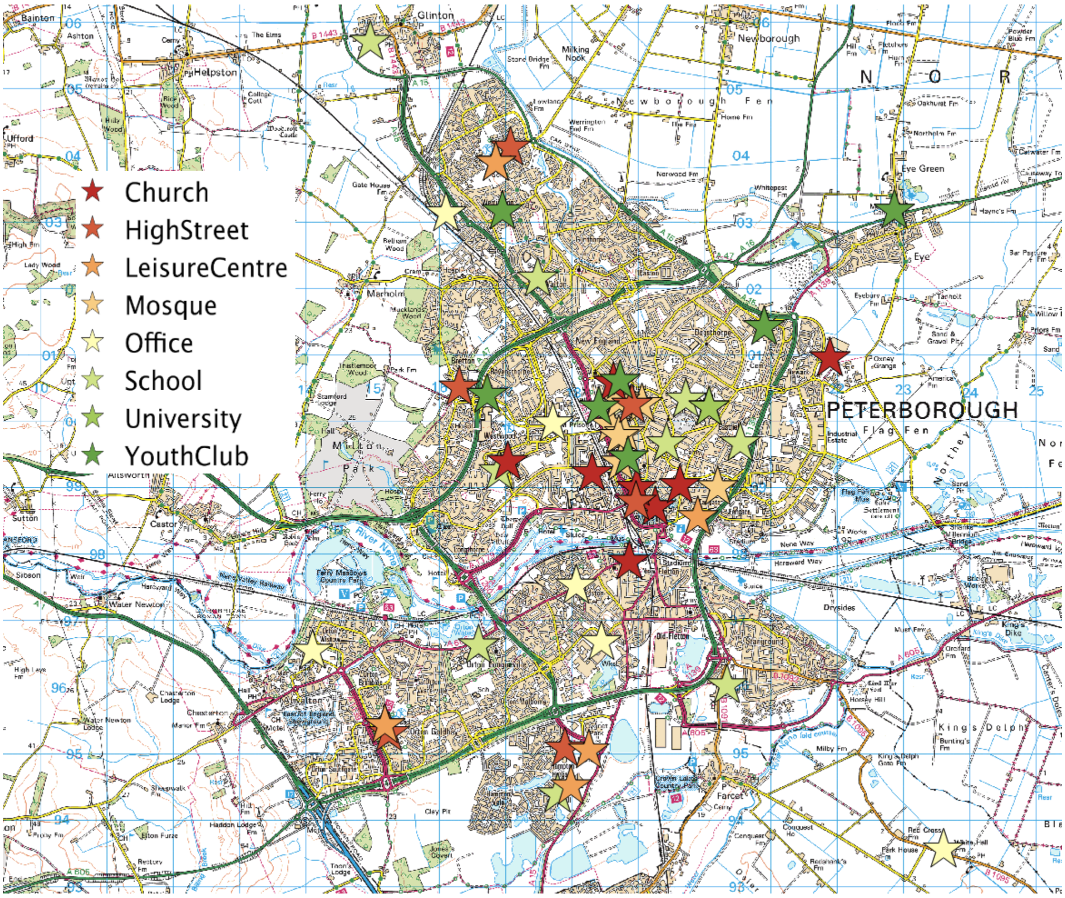

Figure C.1: Locations of settings in Peterborough

Table C.2: Distribution of attributes in people input

Religion	Occupation	Gender	No. People
Muslim	Employed	Male	5
Muslim	Employed	Female	6
Muslim	Unemployed	Male	6
Muslim	Unemployed	Female	5
Muslim	Student	Male	5
Muslim	Student	Female	6
Christian	Employed	Male	6
Christian	Employed	Female	6
Christian	Unemployed	Male	5
Christian	Unemployed	Female	6
Christian	Student	Male	6
Christian	Student	Female	5
None	Employed	Male	6
None	Employed	Female	5
None	Unemployed	Male	6
None	Unemployed	Female	5
None	Student	Male	5
None	Student	Female	6
Muslim	Employed		11
Muslim	Unemployed		11
Muslim	Student		11
Christian	Employed		12
Christian	Unemployed		11
Christian	Student		11
None	Employed		11
None	Unemployed		11
None	Student		11
Muslim		Male	16
Muslim		Female	17
Christian		Male	17
Christian		Female	17
None		Male	17
None		Female	16
	Employed	Male	17
	Employed	Female	17
	Unemployed	Male	17
	Unemployed	Female	16
	Student	Male	16
	Student	Female	17

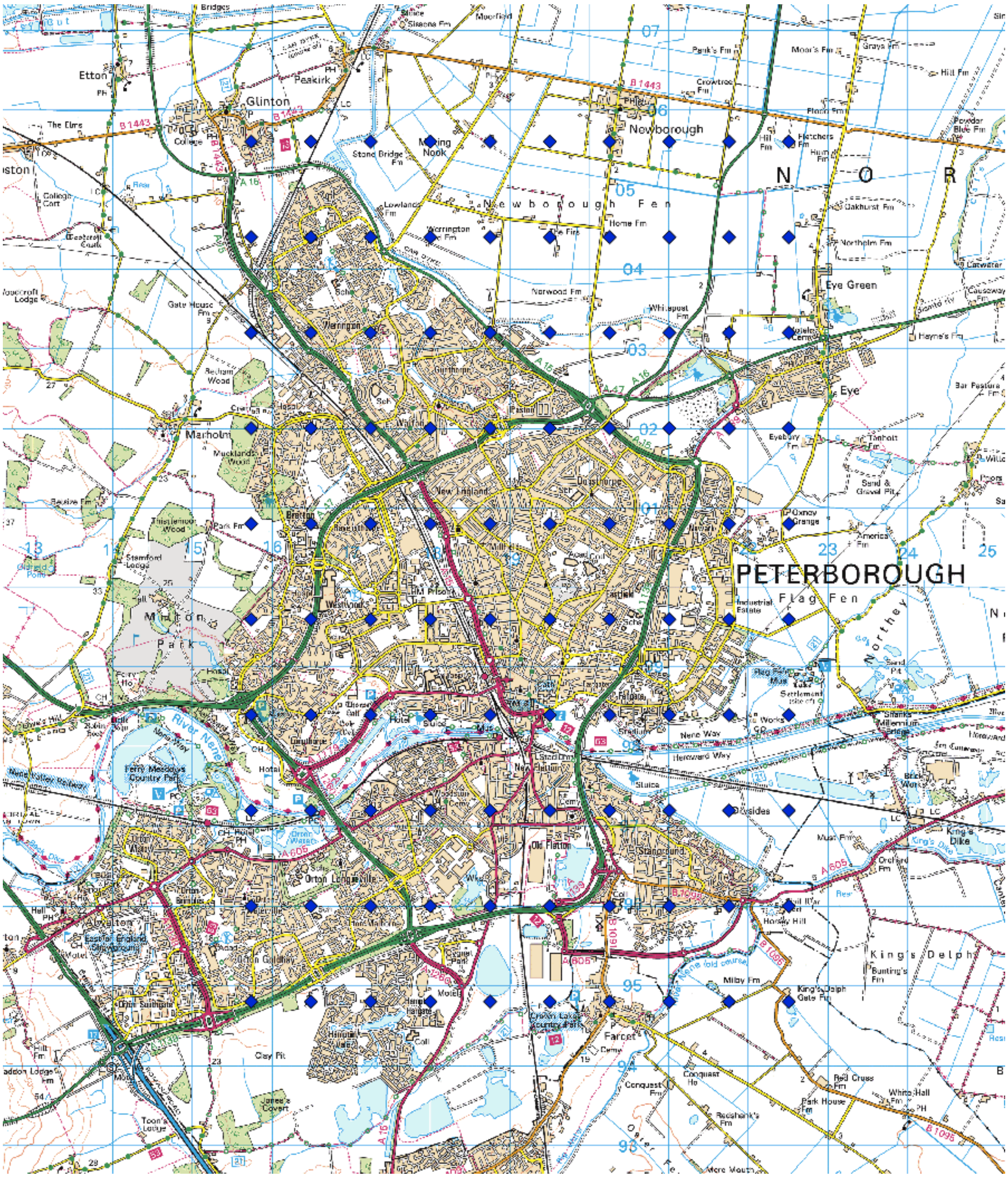

Figure C.2: Location of people's homes in Peterborough