Computational models of emergent organisation in conflict environments

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An agent-based model for emergent insurgent behaviour*

In this chapter we describe a bottom-up modelling approach complementary to our top-down analysis approach in the previous chapter. With this approach we aim to better understand the influence of micro-level dynamics on the transitions of insurgent organisational behaviour and analyse the feedback mechanisms from meso-level and macro-level on these dynamics. We identify the process of radicalisation as a central dynamic of behavioural change. We explore the potential of this dynamic to influence the trade-off between security and efficiency, which is a typical characteristic of conflict environments. The agents' radicalisation process is influenced by the amount of opportunities and threats observed by the agent.

In the previous chapters we analysed the influence of contextual factors on the emergence of insurgent organisations, and outlined important organisational dynamics. In Chapter 2 we described the decentralised functioning of insurgencies that enables emergent patterns of coalescence and fragmentation, which provide resilience to external shocks and disruption efforts. In this chapter, we analyse the ability of insurgent organisations to vary the degree of organisational sophistication from mechanistic to organic, which enables them to either conduct more advanced operations or to increase their flexibility and

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adaptive capacity. These dynamics are poorly analysed by top-down modelling approaches, and highlight the necessity to understand the influence of micro-level interactions, relationships, and their dependencies.

For this purpose, we develop an agent-based model in which agents seek to maximise the reward of their actions. These actions determine whether the agents are aligned to the noncombatant population or to the insurgency. In the model, agents are connected by networks that enable interaction and foster cooperation. Through interactions, the agents are able initiate and establish organisational links to increase the payoff they receive from their actions. The environment exposes opportunities and threats to the agents. The opportunities percolate through networks that connect the agents and are therefore unevenly distributed. Security agents pose a threat to agents that conduct insurgent actions, as they aim disrupt the actions and eradicate the agent reward. Therefore, the model can be extended for other law enforcement purposes, such as policing.

The model enables to explore different scenarios in which the population is more dense, social and insurgent opportunities are more scarce, and COIN actions are more frequent or tactically different. We applied the TRACE-, and ODD-protocol to document the modelling process and to ensure that the model is comprehensive and reproducible. In Appendix C we include these documents, and discuss the implementation and provide additional analysis of our model. Our results suggest to reevaluate the influence of radicalisation on the organisational trade-offs. Theoretical and empirical analysis of static representations of insurgent or terrorist networks extensively analyse the balance of secrecy and efficiency and found both confirmatory and contradicting examples [164]. Our model demonstrates that the interplay of social opportunity, radicalisation processes, and intervention tactics yields transitions in organisational behaviour that impacts the effectiveness of intervention operations.

4.1 Introduction

Terrorists, insurgents and criminals are typical examples of insurgents or insurgent organisations, as their actions may destabilise societies and endanger democracy and peace [165]. Efforts to intervene and control the behaviour of these groups can also cause undesired effects like retaliation, escalation and displacement [166]. Therefore, understanding the dynamics of insurgent organisations (e.g. growth, decline, merging, splitting) is essential in order to maintain a stable society [95, 166]. This dynamic behaviour can be seen as a multi scale phenomenon emerging from multifaceted individual and societal interactions [167]. In fact, the complex interactions between the different systems such as insurgent organisations, law enforcement agencies and the society [166] yield the basic elements of complex adaptive systems (CAS): self-organising, emergence, feedback loops, adaptive realignment and non-linearity [168, 169]. On a micro-level, individual people interact and act relatively autonomous. Different relationships, such as kinship, social, cooperation and financial, connect the individuals [170]. These networks enable self-organising behaviour of the individuals (at the micro-level) and local interactions that yield emerging organisational behaviour (meso-level). For instance, cooperative actions by individuals aim to generate synergy and establish a competitive edge over rivals. At a meso-level, these seemingly in-articulated individual actions, yield a structure that enable insurgent organisations to execute violent actions and/or access to financial and other resources. As the insurgent organisations are embedded in the society (macro-level), observations of events by individuals will influence the intrinsic, self-organising behaviour of individuals and groups. The economic situation or the intensity of security actions can yield positive and negative feedback loops. For instance, a bad economic situation can trigger insurgent behaviour as the scarcity of economic opportunities can nudge people to capitalise insurgent opportunities (opportunities that enable insurgent behaviour are referred to as insurgent opportunities). On the other hand, an increase of law enforcement activities is a typical example of a negative feedback loop as it reduces the attractiveness of insurgent behaviour [21]. These negative feedback loops constrain the growth of insurgent groups within the society [96]. Understanding these dynamics is essential in order to grasp the emergent insurgent behaviour.

In this chapter we will explore how a complex systems perspective can provide new insights into the behavioural dynamics of insurgent organisations. We introduce a modelling approach extending the above insights from complex systems, by integrating criminology, psychology and organisational studies within an agent-based modelling (ABM) approach. Instead of modelling organisations as a whole, we use a bottom-up approach

wherein agents represent individuals with active and adaptive reactions and act driven by self-interest. The resulting model enables at a micro-level the analysis of evolution of individuals and their networks and their potential to form insurgent organisations. At a meso-level it provides an experimentation analysis of the development of insurgent organisations subject to the dynamics of the environment and possible interventions. Finally, it enables a better understanding of the mechanisms leading to social transitions at the macro-level.

In the next section we will provide an overview of related work. In Section 4.3 we introduce our modeling approach, while in Section 4.4 we describe in more detail the agent-based model. Computational results can be found in Section 4.5. Finally in Section 4.6 we discuss the research results and implications for future work.

4.2 Related work

Within complex systems theory, social phase transitions describe dynamics of behavioural change by individuals, groups, or at a system level [171]. A social phase transition could be, for instance, a dramatic change in the way groups organise themselves. These transitions, somewhat similar as phase transitions in physics, are triggered by either slow processes or small events, as these breach the resilience of individuals or groups [172] or alter their motivations [173]. Current studies show promising results applying ABM to analyse how interactions and networks of individuals cause social transitions at multiple levels of a system [88, 174]. These efforts, however, describe dynamics of a population in general not specifically focused on insurgency movements and insurgent organisations. Specific studies are focused on the resilience of criminal [175] and terrorist networks [176–178] using simulation to identify vulnerabilities of these networks. However, the authors of these articles are unable to account for the impact of complex behaviour as they perceive a closed environment with a preexisting network [115].

ABM is a relatively novel method to study social dynamics in conflict environments. The modelling approach proposed in this chapter builds on the efforts described in Section 2.5.3. by integrating fine-grained micro mechanisms and form hypotheses on the causal relationships that cause the emergent phenomena of insurgent organisation.

4.3 Emergent insurgent behaviour

Once insurgency emerges a society experiences its impact at different scales. At a micro-level, a change behaviour by individuals from social accepted to insurgent can be observed. At the meso-level, groups of different sizes and with various activities emerge. Rational

choice theory offers an economic approach to explain how individuals rationally select their actions [179] based on a trade-off of expected benefits and costs. Depending on the intrinsic motivation of the individual, benefits can be associated to acquiring tangible assets such as money, but also non-tangible assets like increase of respect or the spread of fear [180].

4.3.1 Insurgent opinions and actions

Psychological research of radicalisation identifies individual, group and mass mechanisms that lead to justification and eventually encouragement of insurgent behaviour [181]. Empirical research has described two separate processes that lead to polarisation between groups: development of opinions and engagement in insurgent activities [52]. According to Pruyt et al. [182] and McCauley et al. [52] individuals navigate back and forth through different states of radicalisation, which they categorise as neutral, sympathising, justifying, and eventually a moral obligation towards insurgent activities [52, 182]. These individual attitudes are influenced by events at meso-level and macro-level [181]. At meso-level the growth of like-minded groups increases the perception of security by its members and creates obstacles for law enforcement interventions [183]. According to Ganor et al. [183] the extent of public support for an organisation is an important factor to ensure the existence of the organisation. To an extent, repercussions by law enforcement towards radical actions can create a breeding ground for justification of radical opinions. This can lead to an increase of individuals with radical opinions and stimulating polarising developments. This phenom at the macro-level can be seen as a *boomerang* effect [184]. Research focused on deradicalisation and disengagement reveal the importance of social and economic factors to trigger processes that are able reverse the dynamics of radicalisation [173].

4.3.2 Characteristics of individuals and their relationships

At micro-level, individual and cooperative activities are observable. Bichler et al. [185] focus on the networks structures of insurgent organisations and demonstrated the importance of human and social capital for successful insurgent individuals and insurgent networks. Human capital consists of the information, skills and resources possessed by individuals that enable capabilities. Social capital are the *social ties* between individuals that enable them to contact others, share information and initiate cooperation. Carley [178] and Bright et al. [170] emphasise the existence of multilayered networks of social relationships to enable exchange of both tangible and non-tangible assets

Our rational agent model incorporates the psychological and social dimension. Figure

4.1 illustrates the adaptive individual reasoning in an insurgent environment. Individuals perceive opportunities and threats by observing events in their social network and environment. Subsequently the individual (de)radicalises based upon these opportunities, threats, their social interactions and individual success. This influences the radical opinion state of the individual, which is an aggregated factor that represents the attitude towards possible activities. Simultaneously this influences the perceived benefits and costs and thus the expected utility of possible actions. According to the rational choice theory, individuals select the actions with the highest utility. As individuals might have different radical states the perceived utility of their actions will be different. Self-organisation causes that these emergent processes and components are becoming more organised, which yields interdependencies that constrain the autonomy and controllability of the individual behaviour [46, 186].

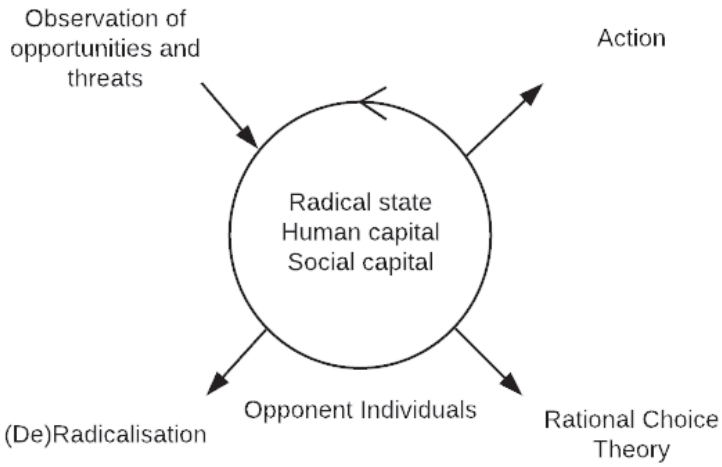

Figure 4.1: Adaptive individual behaviour

4.3.3 Dynamics of "collective" emergent behaviour

The mechanisms underlying collective behaviour of insurgent individuals are illustrated in Figure 4.2. At the micro-level, individuals may cooperate and/or compete proactively as a reaction to the environment, which yields observable behaviour. Similarly to the rational decision making at the micro-level, organisations also have specific goals, which should be

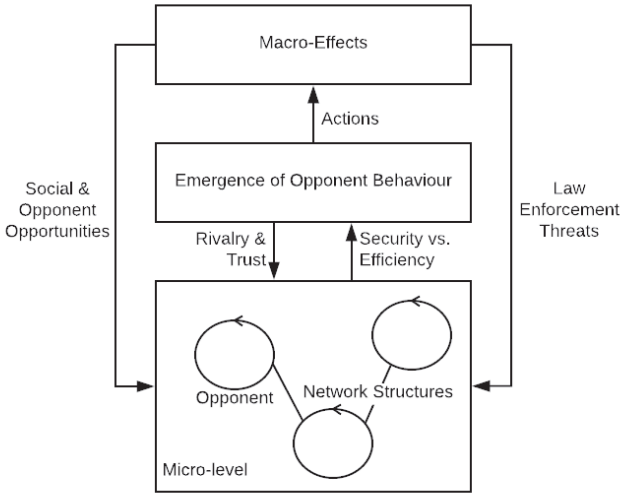

Figure 4.2: Adaptive emergent insurgent behaviour

achieved in the most effective way. As such we will use concepts of the field of organisation theory, which focus on the deliberate and emergent strategies of cooperation, to analyse effective practises by insurgent organisations [187].

The literature on insurgent organisational theory is vast. In particular Framis [188] and Ligon et al. [62] describe a continuum of organisational sophistication. Respectively, this continuum from mechanistic to organic is characterised by a more hierarchical structure and a predictable design with a higher degree of formal rules and decision making, to a flatter structure and unpredictable design of cooperation described as a flexible network.

Whereas a lot of similarities can be found between common and insurgent organisations, insurgent organisations are fundamentally differentiated by the need for secrecy of operations [189]. As previously described, insurgents increases the chance of leakage of information or the vulnerability to infiltration efforts by law enforcement agencies as they intensify their cooperation [180].

Furthermore, insurgent organisations often compete and become rivals [166]. Rios [184] describes a self-reinforcing equilibrium between rivalry among criminal organisations, violence in societies and law enforcement activities. The competition on illegal markets is unstable as they lack formal mechanisms, rules and institutes to cope with disputes, forcing participants to rely on trust [190]. Removing individuals and their relationships

from illicit markets will create new power vacuums and a bigger unbalance within the market. Once organisational forms on illicit markets change from mechanistic to organic, criminals become more individualistic and adaptive [184]. These dynamics increase competition and rivalry between the organised criminal groups.

The above drivers of organisational behaviour play an important role on top of the individual adaptation and self-organisation, which form the basis of our approach. In particular, the emergence of different insurgent organisational structures depends on the feedback mechanisms of opportunity, threat and competition at micro-level and meso-level

4.4 An agent-based model for emergent insurgent behaviour

As illicit operations are covert and illegal, the possibilities are limited for researchers to conduct extensive and detailed empirical research. Moreover, experimentation = with interventions by security organisations is most often undesirable as it may disclose the strategy of the law enforcer, and it may hinder testing alternative intervention strategies. Therefore, we propose an in-silico agent-based simulation environment that allows us to conduct scenario-based experiments. These experiments aim to provide insights into the nature of the underlying complex mechanisms and tp create a better understanding of the evolution of individual and organisational insurgent behaviour. Deriving outcomes of emergent behaviour within this complex system is impossible by a strict mathematical approach due to the amount of interactions, activity, decision rules, states, and variables etc. [191]. An ABM offers the possibility to experiment and estimate the impact of the causal relations and parameters on the behaviour of the system.

An agent-based modelling approach requires a computational representation of the theoretical psychological and behavioural concepts. We use concepts of autonomous decision making, optimisation and distributed systems. Also we translate some psychological and economical theories into the agent-based model presented in this chapter. In our model, agents determine the expected utility of their actions to steer their actions to being either social or insurgent, leading to a population of agents with different attitudes and behaviour. Furthermore, our model incorporates typical ABM characteristics as the agents remember the results of their actions, observe and interact within their social network and environment.

4.4.1 Agent-based modelling

The purpose of our model is to understand how the interactions of insurgents (individuals) yield emergent behaviour and how different conditions effect this behaviour. Our simulation starts with a population of agents with a neutral attitude towards either social or insurgent actions Both these actions can yield a reward for the agent. At each time step the agents certain amount is deducted from the reward of the agents, as they pay a "tax" to the environment. The environment has a scarce amount of social and insurgent opportunities available for the agents to obtain a reward and to pay their respective taxes. This scarcity of opportunities compel competitive behaviour by the individuals. Additionally, actions by security agencies pose a threat to insurgent activity as they can disrupt insurgent activities, which further reduces their reward. At the micro-level, the individual insurgents operate self-interest, autonomously and rationally. To monitor the evolution of the system, different metrics have been identified from literature [192]: insurgent density, ratio between insurgent organisations and individuals, the average insurgent organisation size, the density of the cooperation by insurgents and the effectiveness of insurgent activity [166, 189].

Our model was implemented in NetLogo, and documented according the ODD-protocol to ensure the model is comprehensive and reproducible [191, 193]. The model consists of a population of agents and a contextual environment. The environment is a two dimensional socio-spatial structure that inherits the agents. The environment exerts adversity and competition upon the agents. Law enforcement activities and the environment economic situation of the environments, forced by the scarce amount of opportunities that are available to agents to conduct either socially accepted or insurgent behaviour, challenges the agents to continuously improve their situation. The agents are embedded in underlying networks, that enable them to observe, communicate and cooperate. These networks mimic relationships of individuals in reality [170]. The agents in our model are constructed according a BDI-framework to enable adaptive and reactive agent responses [194]. The ability to move and modify of their network enable agents to compete for an improved position. The agents are able to observe and conduct social and insurgent activities individually or cooperatively with their associates.

4.4.2 Radicalisation and rational choice

Various motives and attitudes were distilled from literature and modeled as agent states: radical opinion state, desire state, intention state [52, 173]. The radical opinion state represents the attitude of individuals towards insurgent behaviour. The desire state determines

whether the agent aims to exploit social or insurgent opportunity. The intention state determines how the agent aims to fulfill this desire, which in case of insurgent behaviour can be either individual or in a network or organisation. Depending on the success of their activities and available opportunity, agents are rewarded for their actions. Agents can initiate bilateral cooperation to create synergy between two agents and increase their individual and collective effectiveness. In order to perform advanced forms of insurgent activities, agents can initiate an organisation to create additional synergy and extent cooperation.

A law enforcement agent is modelled to conduct law enforcement activities. These law enforcement activities attempt to disrupt the activities of agents that conduct insurgent behaviour. At each simulation time step, the modelled law enforcement agencies detect the insurgent activities at a certain rate. They decide on the intensity of their counter actions and choose an action type: direct countering or infiltration. With a direct countering action, the most effective insurgents will be countered. Successful counter actions will drop the reward of the insurgent activity to zero. An infiltration action aims to uncover insurgents by infiltrating in the cooperation and communication networks of the initial known insurgents. Subsequently law enforcement agents attempt to disrupt the insurgent activities of one of the insurgents detected by this infiltration.

The (de)radicalisation process of individuals is modelled by incorporating three feedback mechanisms repeatedly found by empirical research [173, 181, 195]. The first mechanism to change the radical opinion state of an individual is caused by engagement and disengagement in activities [173, 181]. Whenever individuals conduct either social or insurgent actions, their satisfaction (d_n) influenced by the reward of these actions, changes their attitude. For example, when an individual conducts a successful insurgent activity their radical state increases and vice versa. This creates a positive or negative feedback. The second mechanism is found in studies towards social influence in radical groups [195]. The social network enables individuals to spread opinions and ideas, that ultimately drive individuals to create groups that think alike. The third mechanism is caused by the interaction between the individual, the society, and the government [183, 196]. This mechanism, as outlined previously, causes that government actions against radical groups create a backlash in the deradicalisation process of individuals with a radical attitude [183].

The radical opinion state is bounded by extreme values 0 (social) and 1 (radical). The radical opinion state of an agent on a given time ($r_{i,t}$) is the result of its opinion state in the previous time step ($r_{i,t-1}$) influenced by the satisfaction about the reward by activities (d_n), the average radical opinion level (r_{t-1}) of the communication network (G) of the agent and attitude towards law enforcement activities. By multiplying all these factors, the radical

feedback factor ($s_{i,t}$) is obtained. Depending on the social (K) and communication (G) network of the agent, the radical opinion state of the agent is determined by Equation 4.1:

$$r_{i,t}(K, G, d_n) = \min\left(\max\left((r_{i,t-1} + s_{i,t}), 0\right), 1\right) \tag{4.1}$$

The radical opinion state effects the expected costs of insurgent activities. The expected utility (U_i) of an insurgent activity x by agent i (x_i) results from the expected benefits (y_i) and costs (c_i). These benefits and costs are dependent on the cooperation network (H) and organisation network (O) of the agent, which the agent can modify through negotiation with other agents in its communication network (G). The agents deliberately add or deduct cooperation links to control the density of their network, in order to increase the amount of synergy and simultaneously taking into account the expected law enforcement threat [180, 197]. Equation 4.2 expresses the rational behaviour of the insurgents:

$$\max U_i(H, x_i) = y_i(G, H, O, x_i) - c_i(G, H, O, x_i) \tag{4.2}$$

The expected benefits of insurgent activities (y_i) are based on the individual activity x_i, its chance of success (e_{d_c}), and activity of others (x_j) and the added synergy from cooperation (b_c) and added synergy from organisation (b_j) in case the agents in the cooperation network of the agent (H) cooperate in one of both ways (see Equation 4.3). In order to cooperate, agents need communication, such that $H \subseteq G$, with n amount of people in the respective networks. The level of insurgent activity of the cooperator equals x_j. Cooperation links h_{ij} are undirected.

$$y_i(G, H, x_i) = x_i e_{d_c}(1 + b_c \sum_{j=1}^{n} h_{ij} b_j x_j e_{d_c}) \tag{4.3}$$

The expected costs of insurgent activities (c_i) are based on the individual activity x_i and radical state (r_i). The vulnerability of the cooperation network (H) depends on the amount of law enforcement activity (d_{la}), their focus (f_{la}) and success rate (e_{la}). d_{la} and e_{la} are combined by multiplication yielding parameter s. The number of law enforcement disruption actions are determined by the law enforcement rate. The law enforcement focus prioritises specific counter activities. A focus on effectiveness results in targeting the known insurgents with the highest reward, which can be those who have the highest number of connections, those with the most cooperation links, or those at the top of an organisation. An infiltration focus selects one of the cooperation links of each of the potential targets. This causes an exponential risk for cooperation links as cooperation links are targeted by

both policies. Fellow members of a organisation ($\sum_{o=1}^{n} x_o$) pose an additional risk, as they attract attention from law enforcement and create an additional security breach in the network. As agents are aware of these potential counter measures, equation 4.4 expresses the potential costs of the networks and actions of the agents:

$$c_i(G, H, O, x_i, r_{i,t}) = \frac{0.5}{r_{i,t}}(x_i + s(p(\sum_{j=1}^{n} h_{ij}x_j + x_i + \sum_{o=1}^{n} x_o) + q(\sum_{j=1}^{n} h_{ij})^2)) \quad (4.4)$$

A radical opinion state above 0.5 corresponds with justification of insurgent behaviour and will discount the envisioned costs of insurgent activities. Once an insurgent group grows, law enforcement has to focus on a larger group, which discounts the costs of the individual [196]. An optimum in the network will exist if $\frac{0.5}{r} + s > b_c$, as in this scenario the costs of further increasing the cooperation links will exceed the benefits. The parameters for the optimisation of the networks, other than $\sum_{j=1}^{n} h_{ij}$ are updated in the belief stage of the BDI-agent framework. If beneficiary, an agent will attempt to add cooperation links through negotiation with neighbours. Other agents use an equal procedure in order to consider whether additional cooperation links are beneficial.

4.5 Model Analysis and Experiments

Social based computational models require validation to estimate the value of the model output [198]. We both verified and validated our agent-based model in order to analyse the accuracy and applicability of the computational model [191]. Predictive ABM requires real-world data validation to test whether the model output can be generalised to situations in reality. The intended application of our current computation model is to explore the effects of complex adaptive system mechanisms that underlie emergent insurgent behaviour. Therefore a validation process for our computational model was conducted at the dimensions of internal validity and methodological validity [198]. The estimated validity concerns the value of input parameters to construct experiments, model concepts to explore complexities and sensitivity of the input parameters upon the output values. As a result, the output of the model should be interpretable. The initialisation of our experiments demonstrates the power to explore behaviour under different scenarios and study the influence of environmental context to possible emergence of insurgent groups.

The experimental design includes scenarios that vary the amount of opportunity for social and insurgent behaviour, the intensity of the law enforcement activities, and the focus of these activities. Using our simulations the following metrics were collected: amount of

active insurgents, insurgent cooperation density, amount of insurgent organisations, and the collective effectiveness of insurgent activity by individuals. Most interestingly we were able to distinct some expected and unexpected behavioural transitions in the system.

The simulation results indicate that social opportunity is the most important factor to influence the attitude towards insurgent behaviour, see Figure 4.3. The output of the model describes a social phase transition of the system from a society with a low breeding ground for insurgent activities towards a society with a high probability of justification of insurgent behaviour. This transition can be explained by the feedback mechanisms of grievances and mobilisation. However, in our model output the average radical attitude remained stable in scenarios with different amounts of insurgent opportunity. This can be explained by the fact that due to the scarcity of social opportunity, the agents are unable to satisfy themselves conducting social activities. Thus individuals will not deradicalise by government efforts to decrease the amount of insurgent opportunity.

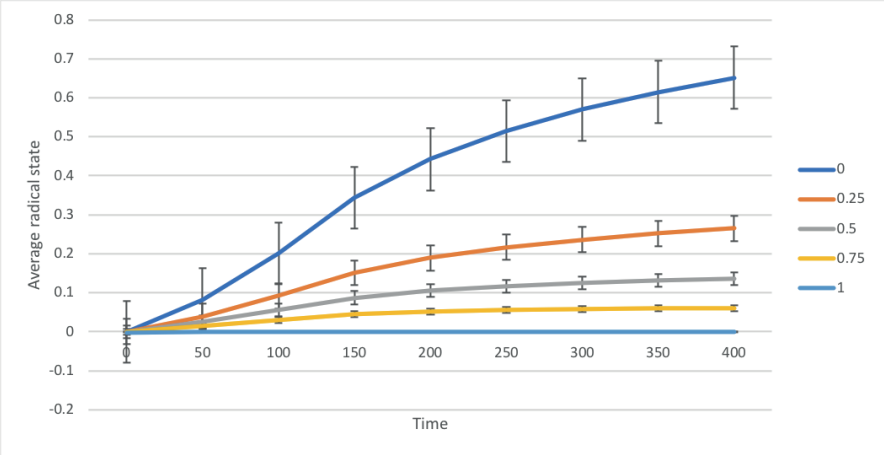

Figure 4.3: Average radical state of agents by various amounts of social opportunity

The metrics of the amount insurgent organisations and insurgent cooperation density also show interesting results. Notably the amount of insurgent organisations decline as the rate of law enforcement activity to insurgent activity increases from 0.1 to 0.2 while the amount of insurgents remain stable, see Figure 4.4. This means that either these insurgents operate in an organisation or, as law enforcement activities threaten their operations, they operate in a loose network to deal with the increased scrutiny. This indicates that the organisation process which determines the amount of cooperation and organisation form might be constrained and subjective to a threshold set by the context in which it takes place

[46, 186]. The spikes and slope in the diagram indicate quick and gradual social phase transitions by agents in organisational manners, which shift from mechanic to organic and vice versa. These organisational manners are influenced by the social network and radical opinion state of the agents and subject to the opportunities and threats posed by the environment. While insurgent behaviour is subjective to these factors, the results show that the behaviour remains relatively unpredictable, while also being resilient to changes by the law enforcement agencies to a certain extend.

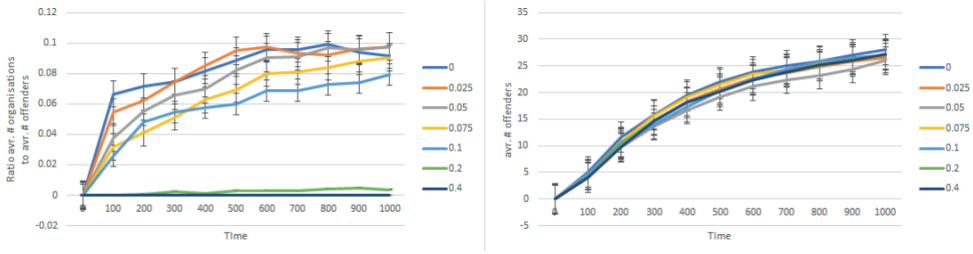

Figure 4.4: Output of simulations with a random neDtwork initialisation of 200 agents. Various intensities of law enforcement activity cause different organisational behaviour; while the average amount of individuals that yield insurgent behaviour remains stable in different scenarios (right), a transition in the collective behaviour is observable as the law enforcement activity increases from 0.1 to 0.2 (left).

Additionally, the ratio of organisations and their size were evaluated under scenarios with different strategies by law enforcement agencies, which either target the most effective insurgents or infiltrate networks. The increased amount of organisations compared to loose networks shows the capability of individuals to adapt to the law enforcement infiltration strategy. Although the emergent behaviour changes, the average effectiveness of insurgents remained relatively stable. This demonstrates the resilience of insurgents to disruptive strategies and complexity of analysing and mitigating insurgent behaviour.

4.6 Discussion and Future Work

The emergent behaviour of insurgent organisations is a challenging topic in academic research and practice. The covertness of insurgent activities and the fact that one cannot experiment with interventions in actual social systems without impacting that system have led us to develop and use in silico experiments. These experiments allow us to test the effectiveness of alternative intervention strategies and comparing the results. Our computational model provides an opportunity to experiment and uncover potential effects of governmental behaviour when intervening in a social system with insurgents. The ability

to reveal complexities regarding insurgent behaviour using an interdisciplinary approach, and the computational agent-based modelling approach allowing us to study mechanisms relevant to subversive organisation, such as competition and law enforcement are the main contributions of our developed methodology.

The application of ABM in this chapter illuminates the merits and disadvantages of this methodology as discussed in Chapter 2. Foremost, the application of ABM in this chapter enabled a computational translation of the concepts found by a interdisciplinary literature study. Compared to other approaches such as analytical modelling or system dynamics, this methodology provides tools to model fine-grained evolution from the level of an individual. To extend the current modelling efforts, advanced ABM could include additional attributes of learning agents and advanced game theoretic based behaviour.

Secondly, the application of NetLogo provided an programming environment for rapid development and accessibility to "non-programmers" [199]. This is especially valuable as most of the scholars of insurgent behaviour have a non-technical background and could experiment with the current model relatively easy. However, the integrated modeling environment of NetLogo prohibits integration of additional modeling methods or program packages, which limits the scalability and effectiveness of the computational model.

However, ABM holds difficulties concerning validity and programmability. The model assumptions and the interactions have a high level of abstractness. Additionally the covertness of insurgent activities limits the amount of data to validate ABM output or estimate the model parameters. Social system ABM are not generalisable beyond the instances that have been examined in the current study. Extensions of current efforts should take these limitations into account. Additionally modeling of dynamics within social systems by ABM is relatively computationally and programming intensive compared to other methods such as system dynamics or statistical modelling [200]. Therefore development of ABM is relatively cost and time expensive. To cope with the issues of validity and costs, development and results of ABM should always be compared with other modeling approaches.

The scope of this chapter was to model the essential characteristics that reflect insurgent behaviour using the concepts of our literature analysis in Chapter 2. Advanced agents or multiple agent types could yield more valid models for specific case studies. Individuals maintained a constant level of activity within the current model. Studies of insurgent behaviour have revealed the possibility to conduct insurgent activities with less impact to hide operations [180, 201]. Additionally the frequency of cooperation and action influences the covertness [180, 189]. Modelling different agent types would enable agents with

different personalities or skills. Modelling different organisation types would enable to compare the effect of interventions on different types of organisations. This would enable analysis of actors with essential roles within networks or organisations [185]. We address this aspect in the following chapter.