

An Agent-based Simulation of Extremist Network Formation through Radical Behavior Diffusion

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Abstract: Understanding how terrorist networks are created and how individuals turn into extremism and then into terrorism is a current subject of interest and a cross-domain research problem since it involves scholars from political sciences, sociology, physics and computer scientists among others. In this paper, an agent-based approach is used to simulate the process of radicalization and creation of a terrorist network, and the link between both processes. Each citizen has several attributes allowing the model to take into account heterogeneous profiles of individual. Furthermore, we model the social transfer that takes place during the interaction of individuals in order to understand how cultural ideas are transmitted. This paper also provides a non-exhaustive but detailed survey of the state of the art on the agent-based terrorist networks modelling.

1 INTRODUCTION

We have seen in the last years an increase of news related to terrorism issues, and it is nowadays considered as one of the main global issues. This is the case of France in particular, where the fight against the terrorism is the second main preoccupation of the population (Lévy, et al., 2016), specially after the terrorist attacks suffered recently. Nevertheless, extremism principles and its corresponding practice implementation – terrorism – have existed long before in another form and with others goals. For example, in the late 20th century some regional terrorist groups as Euskadi Ta Askatasuna (ETA) in Spain or Irish Republican Army (IRA) in Ireland had the main attention of regional media.

Terrorist Networks (TN) works can be studied according to several points of views, methodologies and goals, doing its classification very complex, and could even lead to a publication on this subject. A first look can be taken by type of approach: quantitative vs. qualitative, even if some authors support a combined approach (Crossley, 2010). Quantitative studies try to find a model that explains the system without taking into account the purposeful action of actors. On another side, the qualitative approach focuses on the context in which the relationships are created within the network and

the different types of links. Qualitative studies (Taylor, 2010) try to explain how the particular situation of actors at every moment drives the structure of networks (Hidalgo, 2016). The focus can also be made on the diffusion of behaviors within a network, as (Deffuant, et al., 2002) (Holme and Newman, 2006). Likewise, there are some contributions on terrorist behavior modelling (Taylor, 2010).

Most of the work done on TN takes the network as a macro object where the structure cannot emerge from heterogeneous egos, hence the utility of an agent-based approach. Agent-based simulation models make possible to analyse the macroscopic effects of the heterogeneous agents' interactions. There are some papers in the literature that deal with TN using an agent-based simulation approach. Among them, different topics that can be analysed: radicalization (MacKerrow, 2003) (North, et al., 2004), recruitment (Berry, et al., 2004) (Li, et al., 2015), operational tasks and roles (O'Neil, 2012) (Li, et al., 2015), knowledge acquisition (Moon and Carley, 2007), counter-terrorism (Keller, et al., 2010) (Ilachinski, 2012).

Nevertheless, none of papers described above focuses on the simulation of TN formation process as a subject of study, combining at the same time the diffusion of radicalism, heterogeneous behaviours and micro-macro mechanisms modifying the form of the network. The model presented in this paper deals

with these issues. Moreover, cultural transfers and meeting mechanisms are introduced.

This paper is organized as follows: in section 2 we discuss in detail about agent-based simulation approaches and propose a set of key aspects when modelling TN; in section 3 our model is presented and compared to other papers through these key aspects; then in section 4 show some results. Finally, section 5 concludes the paper.

2 AGENT-BASED SIMULATIONS OF TERRORIST NETWORKS

Since the complexity and variety of agent-based models of TN, we propose in the next paragraph a detail of central questions and common aspects that are studied in the state of the art and discuss about them. The papers analysed here have been selected in order to match all the specifications of our research: and agent-based simulation, the notion of social network and modelling of terrorism.

Each paper focuses more often in a central question that represents the main idea (ex. Counter-terrorism) responding at the same time to some other aspects that can often be common to other papers (ex. How are the links created?). These aspects have been chosen in order to fit with the actual interest in this paper, that is the network formation.

Thus, the following main questions and common aspects have been identified.

2.1 Main Questions

2.1.1 Counter Terrorism

One of the most important questions addressed in TN studies is the development, analyse and simulation of counter-terrorism strategies.

(Raczynski, 2004) introduces the infiltration of counter-terrorist agents within the TN, together with the possibility of some terrorist agents collaborating with anti-terrorist structures. Therefore, terrorist agents can be neutralized leading to the destruction of terror structures. (Ilachinski, 2012) developed an exhaustive framework taking into account different dynamics, and it focuses on the co-evolution of both terrorist and counter-TN, using some measures as entropy, vulnerability or cohesion. Moreover, counter-terrorist agents can detect, infiltrate and capture terrorist agents and/or links. (Tsvetovat and Carley, 2004) simulates the behaviour of the terrorist structure under attacks aiming to destabilize the network. In order to do it, the anti-terrorism agents

have two goals: to learn the structure, tasks and knowledge distribution of terrorists and to remove and isolate terrorist agents. Regarding the first goal, there are 3 ways of intercepting information spread through the TN (random, snowball and socially intelligent traffic analysis). Once the counter-terrorist agents have enough information about the TN, they can attack a random point, the one with the highest degree centrality or cognitive load. (Genkin and Gutfraind, 2011) studies different profiles (lone and trapped wolves, wolf and trapped wolf packs) and scenarios of radicalization through isolation, clustering and mean cell size measures. Occlusion and encapsulation mechanisms are explained from a SNA point of view and presented as counter-terrorism strategies. (Keller, et al., 2010) analyses 4 counter-terrorism strategies and their corresponding response from terrorist agents: leader-focused, grassroots, geographic and random. Terrorist agents modify their parameters in order to protect themselves from these attacks. For example, they increase the cost of creating new links in the case of a leader-focused anti-terrorist strategy, since having too many links is problematic. The same strategy is adopted by terrorist agents in (O'Neil, 2012), where highly exposed terrorist agents are killed or captured et each simulation step. Each terrorist agent has a secrecy attribute, that reflects the agent's ability to remain unexposed. Regarding (Li, et al., 2015), the counter-terrorism aspect is taken into account by allowing the network to be recovered after an attack. The TN can be perturbed by eliminating either a leader or a regular member of a terrorist cell, and the reconstruction process is explained.

2.1.2 Behaviour Diffusion

Modelling the terrorist's behaviour and its diffusion is another approach used for studying TN formation. Behaviour and opinion are two related concepts that can raise some confusions. In this paper, an agent behaviour and opinion is equivalent, and is completely defined through its characteristic vectors of characteristics (cf. paragraph 3.2).

(MacKerrow, 2003) focus in social bargaining process that allows a bottom-up approach for belief spreading. He also introduces the grievance toward a social group using socio-economic and cultural-penetration metrics, and the notions of social welfare and social capital, as well as a social pressure. (Berry, et al., 2004) developed a whole framework to model behaviour diffusion. Agents' disgruntlement evolves according to its personal network, society attitude, mosques they are member

of and finally the clique behaviour, that is the behaviour of agents surrounding it. Disgruntlement changes following a linear reinforcement and/or linear attraction. (Genkin and Gutfraind, 2011) model the pressurability on an agent, that measures how fast an individual changes his opinions according to his friends' ones, an essential notion in order to model how a moderate agent becomes a radical one.

2.1.3 Operations, Tasks and Roles

An important part of TN studies is focusing about the objective of their members. Some papers take into account the organization of a terrorist attack by modelling different roles, tasks or necessary operations in order to perform a mission.

(O'Neil, 2012) and (Li, et al., 2015) develop a whole framework dedicated to operations, roles and tasks, with hierarchical structures and leader selection process. (Ilachinski, 2012) developed a model of TN as a complex adaptive system, with very complex roles, missions and dynamics. (Raczynski, 2004) uses a probability of terrorist attack based on the size of the TN as well as the number of existing terrorist-supporting structures. (Tsvetovat and Carley, 2004) model different tasks and its assignation to agents through a meta-matrix. Concerning (Moon and Carley, 2007), the objective of individuals is knowledge acquisition (a precondition to a terrorist attack).

2.1.4 Recruitment

In order to become a terrorist, a radical agent in (Berry, et al., 2004) has to belong to a radical clique and to be contacted by a "bridge" agent, that is an agent who allows to interact with a terrorist organization. A similar idea is used by (MacKerrow, 2003), where an agent has to be radicalized before contacting a terrorist organization. Moreover (MacKerrow, 2003) proposes a parameter of "self-motivation toward terrorism" that allow some agents to require more or less active recruitment. (Li, et al., 2015) introduces a recruitment cell that communicates with other cells in order to know about human resources needs. They define also the processes of recruitment and a parameter of recruitment cost. (O'Neil, 2012) take also into account a recruiter role and proposes a mechanism of replacement of a leader.

2.2 Common Aspects

In order to answer the previous questions, we have

identified some more general aspects tackled by authors. These aspects are not the main issue of respective papers but they are however necessary to answer some central questions. The first three (Link creation, Structure and process relation and Topology) correspond to network formation related issues, and the last two (Multilayer and In/Out data) are more methodological.

2.2.1 Link Creation

This is the most important step in a simulation model of network formation.

(Berry, et al., 2004) calculates the weight of a relationship between two agents, based on the disgruntlement level of agents and their personal traits. A link is created from a certain threshold. (MacKerrow, 2003) uses a social bargaining between agents since they seek to get into a leader's network, that is someone with a lot of relationships, so creating a link has a "social cost". (Raczynski, 2004) creates a link when agents are spatially close, and this is more likely when they are in cities, an abstract agent of his model. (North, et al., 2004) focus on the inference from incomplete network data, together with some social network rules and detailed documentation about interactions between agents. (Ilachinski, 2012) link dynamics is based in one hand on the theory of communication of (Monge and Contractor, 2003), that is social reward and mission gain, and in the other hand in an equation calculating the perceived risk of creating a link. Furthermore, agents have some motivations to create or erase links, as acquiring mission-required resources or the perceived risk of discovery. (Tsvetovat and Carley, 2004) and (Moon and Carley, 2007) give a detailed equation to select the best candidate to create a link to and also a probability of interaction based on differences between agents' attributes, social distance and spatial proximity. (Genkin and Gutfraind, 2011) follows the "never swap a good friend" rule. This is based on homophily, magnets (the equivalent of social spots in this paper), degree budget (maximum of connections by agent), transitivity and an attrition parameter measuring the migration rate of radicals among different communities. (Keller, et al., 2010) applies the preferential attachment principle. (O'Neil, 2012) shows a formula calculating the weight of links, based on agents' roles and locations. Moreover, there is a mechanism controlling the macro behaviour of the network, depending on the success of terrorist operations. (Li, et al., 2015) specifies some scenarios where a link can be created.

For example, when an agent transfers a resource from a cell to another, links created by terrorist recruitment cells when they capture new terrorist, and the designation of a new leader.

2.2.2 Structure and Process Relation

Some authors explain how network's structure and agents' behaviours interact, independently of link creation process.

For example, in (O'Neil, 2012) the network structure changes according to the issue of operations. In (Li, et al., 2015), the network is re-structured after the counter-terrorism attacks. (Genkin and Gutfraind, 2011) identifies radical profiles as well as counter-terrorism strategies using SNA measures and the position of agents in the network. Agents in (Moon and Carley, 2007) change its behaviour and goal according to its position in the space, since they seek for knowledge and resources distributed over the geographical space. (Berry, et al., 2004) models an inter-relation between cliques and agents' behaviours, that is these two entities influence each other at the same time. Finally, the structure of the network in (Ilachinski, 2012) depends on roles, operations and the battlefield context.

2.2.3 Network's Topology

Regarding the structure of the obtained networks in analysed papers, it is difficult to establish a consensus about the actual topology of TN.

(MacKerrow, 2003) (Berry, et al., 2004) (Tsvetovat and Carley, 2004) (Genkin and Gutfraind, 2011) (Li, et al., 2015) obtain cellular/cliq based networks. (Raczynski, 2004) obtain a tree structure. (Moon and Carley, 2007) follows a spatial structure. (Keller, et al., 2010) uses a preferential attachment rule so he obtains a scale-free network. Finally, (North, et al., 2004) (Ilachinski, 2012) (O'Neil, 2012) allow their model to create any kind of topology, depending on parameters or existing prior data.

2.2.4 Multilayer Networks

As discussed before, qualitative approaches are interested in the type and motivation of relationship between individuals, and multilayer structures are the natural way of taking into account these details. Furthermore, there are more and more mathematical formalizations of multilayer networks (De Domenico, et al., 2013).

Regarding terrorist multilayer networks,

(MacKerrow, 2003) defines kinship, religious, organizational and friendship layer. (Berry, et al., 2004) observes the following layers according to the weight or strength of the link between individuals, in ascending order by strength: world, mosque, acquaintance, strong bonds and clique. (Ilachinski, 2012) proposes a more complex layer division, with 3 different layers oriented to a counter-terrorism strategy: genotype (primitive agent behaviour), phenotype I (emergent agent behaviour) and phenotype II (emergent squad and force behaviour). Moreover, agents in his framework perform actions in two different spaces: physical and information one. Finally, (Tsvetovat and Carley, 2004) and (Moon and Carley, 2007) uses a meta-matrix approach allowing to take into account agents, knowledges, resources, locations and tasks.

2.2.5 In/out Data

(Berry, et al., 2004) does not precise any input data, however a similar paper (Berry, et al., 2003) discusses about using available data from urban street gangs as an analogy of terrorist groups. (MacKerrow, 2003) uses census data, interviews and GIS data in his model in order to initialize attributes like ethnography, income, religion, educational degree, etc. Likewise, the allegiance vector is built from qualitative data. (North, et al., 2004) generates a TN from a sample of a given network. (Moon and Carley, 2007) describes the input data set as the result of an automatic process of analysis of unclassified documents like newspaper articles or intelligence reports using AutoMap text analysis tool. Regarding spatial information, they hand coded corresponding latitudes and longitudes. (O'Neil, 2012) extracts information from JJATT database (doitapps.jjay.cuny.edu/jjatt/) in order to define agent's roles. Moreover, since his model mimics real world networks, the Jemaah Islamiyah network from JJATT was used as initial network. (Keller, et al., 2010) models counter-terrorism strategies based on empirical ones. (Ilachinski, 2012) doesn't put any data in his model but the topology and dynamic of his model have been developed following operational and ground knowledge. (Genkin and Gutfraind, 2011) does not use any real data as input of the model, however the results are partially validated by empirical data and radical profiles are based on empirical cases of home-grown self-starter terrorism. This data comes from some available datasets as Lexis-Nexis, TRC or START among others. NetWatch package, presented in (Tsvetovat and Carley, 2005) and (Tsvetovat and Carley, 2004),

generates synthetic TN based on real network data. As case of study, they show the generative model of the September 11th hijackers dataset collected by (Krebs, 2001). Real data is also used to describe the terrorist attack strategies, that is sequences of tasks, resource management, etc.

Table 1 sums up the precedents paragraphs.

3 MODEL DESCRIPTION

The model described below is a GAMA implementation based on (Berry, et al., 2004). GAMA is a modelling and simulation platform (Grignard, et al., 2013) that allows modellers and experts in numerous domains (ecology, social sciences, etc.) to build complex models without strong computer sciences skills, thanks to high-level modelling language, supporting the integration of multiple level of agency and realistic environments.

Nevertheless, even if some aspects as social spot stickiness or social similarity (cf. next paragraphs) are common to (Berry, et al., 2004), the main goal of this paper is to show a mechanism of network formation and not only the recruitment of terrorist through clique detection. Moreover, this paper focuses on cultural vector or social transfer and meeting mechanisms.

3.1 Entities

3.1.1 Social Spots

Social spots represent places where behaviour diffusion takes place. During the simulation, agents can attend a social spot. In order to choose a social spot, a stickiness (Berry, et al., 2004) percentage is computed. This value depends on agent personality and social spot ideology. A social spot ideology is defined from its members' zeal and cultural vector, and from its own cultural vector. This last value can represent the personality of the social spot leader, or some trait well known about the social spot. For example, one can have a certain a priori about a social place independently of the existence of a leader.

3.1.2 Agents

An agent's personality is defined by fixed attributes like age, sex, religion, etc. and a cultural vector similar to the allegiance vector presented by (MacKerrow, 2003) that describes cultural traits, that is the opinion about some specific

organizations, countries, etc. Moreover, an agent has a value of zeal, which is defined as a measure of agent's political violence (Genkin and Gutfraind, 2011). Zeal value allows to make a difference between an extremist passive agent and an active one. An agent with a very high zeal value is ready to becomes a terrorist. This is similar to the disgruntlement value described by (Berry, et al., 2004). Zeal evolves every time two agents meet, in function of their current zeal values. For example, if both agents are radicals, they mutually increase their zeal.

"Society" is a special kind of agent based on (Berry, et al., 2004) that influences agents at each simulation step. This influence has an impact in the agent's cultural vector depending on its social pressure sensibility value. Society agent allows us to model the macro mechanism taking place in the network formation process.

3.2 Dynamics

The dynamic of the model is fully described by 3 processes: dynamic related to the social network that is the formation of links, the attending to a social spot and the social transfer between agents. These dynamics are computed sequentially (discrete event simulation) Every dynamic influences the other, since for example an agent will create a link with other agent depending on a score taking into account if they are in the same social spot and the similarity between their cultural vectors.

3.2.1 Link Creation

The model allows agents to meet in different ways. First, they can do random meetings with a certain probability (Tsvetovat and Carley, 2005). Otherwise, there are two meeting or dynamic mechanisms:

a. According to the social similarity

Here, a social similarity measure is used to decide whether two random agents are able to create (or remove if below a threshold) a link between them within the social network. Social similarity is based on the similarity equation presented in (Berry, et al., 2004) and network measures like shared friends, homophily and degrees.

b. According to agent's opinion

The model presented in (Holme and Newman, 2006) is used to compute the dynamics of opinions. At each simulation step, an agent has two possibilities: Either to switch one of his links by another one (that is remove one link and create another one) that allow it to connect with an agent

having the same opinion or to replace his own opinion by the opinion of one of its neighbours, keeping the same link.

3.2.2 Attending a Social Spot

An agent can belong to a social spot if a “stickiness” score is high enough to attend it. This score is based on (Berry, et al., 2004) with a modification allowing to take into account both fixed characteristic and cultural vectors.

3.2.3 Social Transfer

The social transfer mechanisms allow agents to communicate and exchange their cultural values, what will have an impact in the other dynamics (creating links and attending a social spot).

The current version of the model described here uses Axelrod model for the dissemination of culture (Axelrod, 1997), which allows to change one value of the cultural vector at each interaction.

4 RESULTS

The following results show how a network is formed through a radicalization process depending on the social meeting mechanism used. The red dots represent radical people and the white ones are neutral people. For these simulations, we have initialized a population of 20 agents, 17 of which are neutrals and 3 radicals. This size corresponds to a neighbourhood scale simulation, where opinions can diverge, be homogenized, evolve, etc. We think this is a good trade-off between a large-scale simulation as a region or inter-countries simulation (MacKerrow, 2003) or a more restricted simulation within a small group of 5-10 participants as many sociological works.

Cultural and fixed vectors and zeal values are initialized randomly between $[-1,1]$, and social pressure sensibility is minimal in the case of radical agents, that is they are totally convinced in their cause and can't be neutralized. In this simulation, there is a radical social spot and a neutral one, so its cultural vectors correspond to its ideologies. Moreover, the society agent influences some random agents at each simulation step. This influence changes some values of cultural vector in order to radicalize the agent.

As explained above, there are two mechanisms for agents to meet. The first one, based on a social similarity metric, generates a network with two main

components: a clique of neutral people and another one of radicals Figure 1.

This is an expected result since the model is based on Berry's (Berry, et al., 2004) which aims to show the clique based structure of a TN. More interesting is the evolution of the structure through the simulation. One can observe that on $t=75$ there are two communities of neutral people. This is due to the existence of two different social spots, but there is a homogenization process over the simulation that bring together all neutral people in one single clique. Concerning radical people, there is a one person who was radicalized between $t=0$ and $t=75$. Nevertheless, radicals don't create a network as quickly as neutrals. This can be explained with the zeal parameter. Actually, one can be radical because of different raisons, but the probability of creating a link between two radicals is higher when the zeal level is similar, that is when they are ready to become an actual terrorist, meaning ready to perform a terror act. There are also some contacts between radical and non-radical people, but they become increasingly rare.

Figure 2 corresponds to the network formation process using Axelrod combined with (Holme and Newman, 2006). The obtained structure is completely different compared to the previous one. People are more dynamic and choose their contacts giving more importance to the opinion. Opinions change in a more dynamic way, and the result is a population with more radicals. Some people keep their opinion and remain isolated from the main component, that was not possible with the previous model. This can be explained because social spots have less impact on people behaviour, since people are less devoted to the behaviour supported by social spots and more on people's one.

5 CONCLUSIONS

This paper describes a model of terrorism network construction, with mechanisms allowing the diffusion of cultural values, social meetings and radicalization. We showed how the diffusion of radical behaviour is related to the formation of the network and vice-versa.

Axelrod model is used for the cultural transfer between agents. However, other models of social transfer as (Schleussner, et al., n.d.) (MacKerrow, 2003) (Deffuant, et al., 2002) are being developed and adapted to our model in order to compare the resulting networks.

Some important questions in terrorism as

operations, tasks and roles could be added to our model as separated modules. Similarly, we could study the multilayer structure of the society, allowing us to discover more details about the radicalization process.

Finally, the model is easily adaptable to others multi-agent platforms or high-level computer languages

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APPENDIX

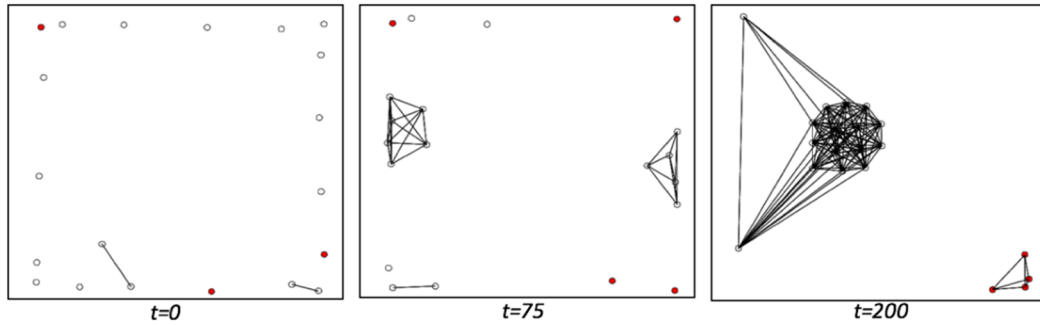


Figure 1: Network formation using Axelrod model of social transfer combined with social similarity based mechanism of meetings.

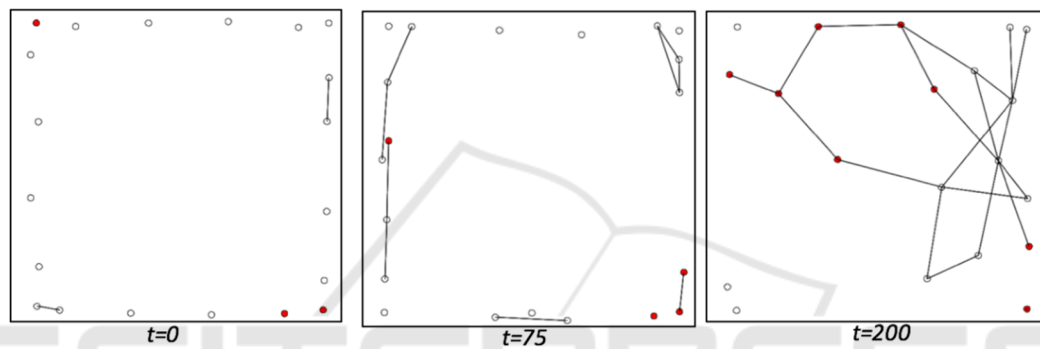


Figure 2: Network formation using Axelrod model of social transfer combined with Holme's model (Holme and Newman, 2006) of opinion diffusion.

Table 1: Detail of key features by paper.

	(MacKerrow, 2003)	(Berry, et al., 2004)	(Raczynski, 2004)	(North, et al., 2004)	(Ilchinski, 2012)	(Tsvetovat & Carley, 2004)	(Moon & Carley, 2007)	(Genkin & Gutfraind, 2011)	(Keller, et al., 2010)	(O'Neill, 2012)	(Li, et al., 2015)
Link creation	Social bargaining	Similarity formula	Space distance	Interaction rules	Social reward, mission gain and perceived risk formula	Best candidate and interaction formula	Best candidate and interaction formula	<i>Never swap a good friend</i>	Preferential attachment	Similarity formula	Resource transfer, recruitment or new leader
Initial topology	Algorithm of Jin et al. (Jin, et al., 2001)			Any	Any		Latitudes and longitudes			Any	Cellular
Obtained topology	Cellular	Cellular	Tree	Any	Any	Cellular	Spatial	Cellular	Scale-free	Any	Cellular
Operations			P(attack)		Dedicated framework	Meta-matrix				Dedicated framework	Dedicated framework
Behavior diffusion	Grievance, social welfare, etc.	Dedicated framework						Radicalization			
Structure/Process		Dedicated framework			Operations issue		Knowledge and resource seeking	Radical profiles		Operations issue	Counter-terrorism attacks
Multilayer	Kinship, religious, organizational and friendship	World, mosque, acquaintance, strong bonds and clique			Genotype, Phenotype I and II, physical and information	Meta-matrix	Meta-matrix				
In/Out	Census, interviews and GIS	Urban street gangs		Available sample		(Krebs, 2001)	Newspapers and intelligence reports	LexisNexis, TRC, START		JJATT	
Counter-terrorism			Infiltration, collaboration		Dedicated framework	Wiretap and CT attacks	None	CT attacks	Dedicated framework	CT attacks	CT attacks
Recruitment	Yes	Yes								Yes	Yes