

# Model Documentation for the IVEE Radicalisation Simulation

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## 1 Overview

The model is an individual-level state transition model comprising four states and two transitions. The four states are:

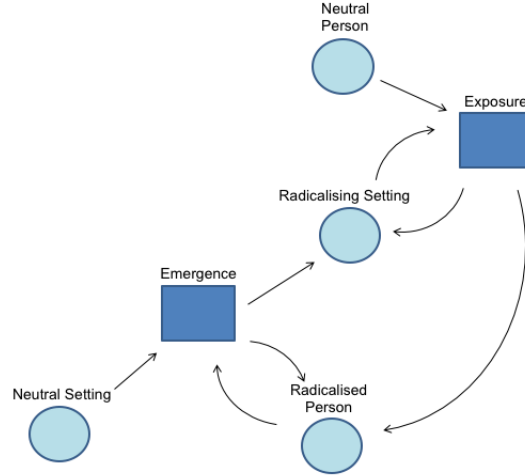
- Neutral person
- Neutral setting
- Radicalised person
- Radicalising setting

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 radicalising setting as inputs, and a radicalised person and radicalising setting as outputs.
- Emergence: this has a radicalised person and a neutral setting as inputs, and a radicalised person and a radicalising setting as outputs.

The arrangements of the states and transitions can be depicted as a Petri Net, as in Figure 1.



**Figure 1:** IVEE Petri net for radicalisation

## 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 between 0 and 1. The higher the number, the greater the person's propensity for terrorism. 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 radicalising 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.

### 3 The Setting Agent

The Setting agent has the following attributes:

- Name
- Radicalisation Level,  $r_j$ : this is a number between 0 and 1. The higher the number, the more radicalising the setting is. Radicalisation level 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. The way a setting's size is measured must be consistent for settings of the same type. It is used when calculating the attractiveness of a setting to a person (described below).
- Collective Efficacy Coefficient,  $\omega_j$ : 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

## 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:

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 direct distance 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:

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

where the  $\eta$  values enable different weighting to be given to each attribute. For the default version of the model these are set to 1, so 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 1.

**Table 1:** Age coding scheme

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

$\alpha$  and  $\beta$  are parameters of the model.

There are two exceptions when generating activity fields:

- 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.

## 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. 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.

## 6 The Transitions

### 6.1 Emergence

The emergence transition occurs when a setting forms a significant part of a radicalised person's activity field — that is, for any setting  $j$  for which  $f_{ijk}(t) > \tau_1$  for some time threshold  $\tau_1$ , where person  $i$  has a significant propensity  $p$  for some terrorist behaviour (so  $p_i(t) > \varepsilon$  for some propensity threshold  $\varepsilon$ ).

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

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

for  $\tau_1 = 1$  hour and  $\varepsilon = 0.1$ , where  $p_i(t)$  is the propensity of person  $i$  for terrorism at time  $t$ ,  $n$  is the number of people  $i$  such that  $f_{ijk}(t) > \tau_1$ , and  $\omega_j$  is the collective efficacy coefficient of the setting.

### 6.2 Exposure

The exposure transition occurs when person  $i$  spends a non-zero amount of time in a radicalising setting  $j$ . The exposure transition is defined to be the way the three variables of cognitive susceptibility, radicalising influence, and

propensity (comprising morality and self-control) interact. The following function is used for the exposure transition in this model:

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

where  $x_1(i, t)$  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 radicalising settings that person  $i$  has had at time  $t$ . By default,  $x_3(i, t)$  was defined as the mean average of the radicalisation level of each setting visited by person  $i$  that time step.  $x_3$  is transformed into a  $z$ -score using  $\mu = E(p_i(t)) = 0.5314549$  and variance 0.04.

## 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 radicalisation levels of the settings visited by each person
4. Call the emergence transition
5. Calculate the amount of exposure to radicalising settings each person experiences, and transform to a  $z$ -score
6. Call the exposure transition
7. Record radicalisation levels and propensities in output files.