To Radicalize or to Deradicalize? Is that the Question?

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Abstract

Radicalization and deradicalization are deeply uncertain dynamic processes. Exploring and analyzing many plausible futures and assessing the robustness of policies to reinforce desirable evolutions seem more useful for such processes than trying to predict their precise development over time and optimize the associated policy response. This paper illustrates how the combination of System Dynamics Modeling and Exploratory Modeling and Analysis could be helpful for exploration and decision making in case of deeply uncertain dynamic issues such as de/radicalization processes. In this paper, different System Dynamics models about radical and non-radical activism are presented and analyzed, both separately and jointly, but always under deep uncertainty. The different models are treated as alternative dynamic assumptions about how/why activism may become more or less extremist/harmful. These dynamic assumptions are included as structural/model uncertainties and are combined with many other uncertainties in order to generate a large ensemble of plausible scenarios. Finally, this ensemble of plausible scenarios is used to test policies for fighting radicalization under deep uncertainty. The 'hot teaching and testing cases' related to the models used for this analysis are provided in the appendix.

Keywords: Exploratory System Dynamics, Deep Uncertainty, EMA, ESDMA, Radicalization, Deradicalization

1 Introduction

1.1 Radicalization & Deradicalization

Radical activism and (further) radicalization are complex and uncertain risks: these slumbering phenomena could be self dissolving, unsolvable or could be the potential breeding ground for acute and/or chronic crises (Pruyt 2010b). De/radicalization of animal rights activism and the rise and fall of radical versus non-radical actions against dictatorial regimes in Tunesia, Egypt, Lybia, etc. are interesting examples of such unpredictable processes. It is precisely the combination of dynamic complexity and deep uncertainty that makes them unpredicable but nevertheless 'explorable'.

Dynamic complexity is found in situations where cause and effect are subtle, and where the effects over time of interventions are not obvious (Senge 1990). It arises, among else, from the complex interactions of systems, markets, institutions, products, regulators, (groups of) actors, and policies/regulations. And *deep uncertainty* is found in situations where analysts do not know, or the parties to a decision cannot agree on *(i)* the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future [e.g. different drivers and underlying structures than today], *(ii)* the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models, and/or *(iii)* how to value the desirability of alternative outcomes (Lempert, Popper, and Bankes 2003).

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1.2 Methodology: ESD x EMA = ESDMA

Conventional forecasting, planning, and analysis methods are not suited for dealing with dynamic complexity (Senge 1990) and even less so for dealing with deep uncertainty: prediction of dynamic behaviors and certainty about probabilities, validity, and optimality cannot be obtained for (future) multi-dimensional systems characterized by high degrees of dynamic complexity and deep uncertainty. Moreover, improving models by increasing the level of detail or their size does mostly not help much: after all, 'all models are wrong [but] some are just more useful' (Sterman 2002). It may even be harmful if there is little time to act or uncertainties cannot be reduced, since it is very time-consuming and may generate the illusion that all uncertainties can be and are reduced.

Instead of focussing on predictability, optimality, and attempting to develop ever more detailed models validated upon past conditions, it may be more useful to develop alternative models, *explore* different model formulations and a plethora of uncertainties, and test effectiveness and robustness of policies in the face of these parametric and structural uncertainties.

Traditionally, System Dynamics (SD) is used for modeling and simulating dynamically complex issues and analyzing their resulting non-linear behaviors over time in order to develop and test the effectiveness of structural policies. Mainstream System Dynamicists have assumed for decades that uncertainties are omnipresent, and hence, that trajectories generated with SD simulation models should not be interpreted quantitatively as point or trajectory predictions, but that they should be interpreted qualitatively as general 'modes of behavior'. And although univariate sensitivity analysis and multivariate sensitivity analysis are mostly performed, they are mainly aimed at validation close to the base case behavior – not exploration over the entire uncertainty space. It seems therefore that in traditional SD the omnipresence of uncertainties is accepted but that they are not really explored or explicitly taken into account.

However, SD models may also be built specifically for the purpose of exploring the potential influence of uncertainties on dynamically complex issues. Such Exploratory System Dynamics (ESD) models are preferably fast-to-build and easily-manageable models, and consequently, rather simple and highly aggregated. ESD is an interesting approach for exploring uncertainties, and testing the effectiveness of policies in the face of these uncertainties. However, ESD in isolation may be insufficiently broad and systematic to firmly base policymaking under deep uncertainty on.

But the combination of ESD with Exploratory Modeling and Analysis (EMA – a methodology for exploring deep uncertainty and testing the robustness of policies – see subsection 2.2) may be useful and sufficient for broadly and systematically exploring and analyzing plausible dynamics under deep uncertainty, and for testing the effectiveness and robustness of policies without neglecting deep uncertainty and dynamic complexity. EMA consists of using exploratory models (not necessarily SD models) for generating tens of thousands of scenarios (called an 'ensemble of future worlds') in order to analyze and test the robustness of policy options across this ensemble of future worlds – in other words whether the outcomes are acceptable for all transient scenarios generated by sweeping the entire multi-dimensional uncertainty space. As such, it can be used to generate insights and understanding about the functioning of systems and the robustness of policies, by taking deep uncertainty seriously into account (Lempert, Popper, and Bankes 2003) (Agusdinata 2008). In EMA, the question is not 'when to measure more' nor 'when to model better', but 'how to explore and analyze dynamically complex systems under deep uncertainty', and 'which policies do effectively and robustly improve system behavior under deep uncertainty'.

Since EMA requires handy models for generating (thousands of) plausible scenarios, and ESD requires methods for exploring deep uncertainty, they are actually natural complementary allies (Pruyt 2007), and could be combined as Exploratory System Dynamics modeling and Analysis (ESDMA). Examples of ESDMA can be found in (Lempert, Popper, and Bankes 2003), (Pruyt 2010b; Pruyt and Hamarat 2010a; Pruyt and Hamarat 2010b), and in these proceedings in (Pruyt, Kwakkel, Yucel, and Hamarat 2011; Pruyt, Logtens, and Gijsbers 2011; Pruyt 2011a; Kwakkel and Slinger 2011).

1.3 De/Radicalization and ESD & ESDMA

As stated above: De/radicalization processes are mostly too complex and uncertain to be predicted whether or not models are used. Models may nevertheless be useful to explore the extent of plausible evolutions. One way to generate different plausible evolutions is to focus on uncertainties from start to finish and sweep the entire uncertainty space. The enormous amount of scenarios generated that way can often be clustered. Similar patterns may then be represented by one representative scenario. Both the full set of scenarios and the reduced set of scenarios may then be used to gain a better understanding of plausible evolutions. A better understanding of those plausible evolutions may lead to better –plausibly counter-intuitive[1]– policies. And the appropriateness of these policies may as well be tested over the entire ensemble of scenarios. This is what will be illustrated in this paper.

1.4 Organization

First, the methodology is further explained in section 2. Second, a first de/radicalization model is introduced and used for ESDMA in section 3. Then, a second de/radicalization is introduced and used for ESDMA in section 4. An ESDMA on both models and various structural variants is presented in section 5. Finally, some concluding remarks are formulated in section 6. 'Hot' teaching and testing cases related to the SD models are included and referred to in appendix A.

2 Methodology: Exploratory System Dynamics Modeling and Analysis

2.1 Exploratory System Dynamics (ESD)

Exploratory System Dynamics (ESD) refers to the development and use of fast-to-build and easy-to-use SD models for 'quick and dirty' exploration of (a plethora of) possible behaviors and plausible scenarios, and for developing a rough idea about the effectiveness –and to a lesser extent the robustness– of potential policies.

As such, it may be used to quickly explore plausible behaviors with a relatively simple model –or relatively simple models– without explicitly aiming to uncover *the* structures underlying the real issue and forecasting *the* behavior or *the* probabilities of the behaviors.

The focus of ESD lies then on testing whether behaviors of interest (e.g. plausible trajectories that require attention) can be generated (at all), on exploring plausible types of behaviors, and on identifying policies that may be effective. Traditional tools such as scenario analysis, risk analysis and what-if analysis can be used in ESD too, but in view of a different goal than in traditional SD (exploration instead of model validation).

ESD could be used for generating interesting behaviors, plausible trajectories that require attention, test whether specific behaviors can be generated at all, etc. It cannot be used to make predictions or derive firm conclusions about specific values or sets of conditions that may lead to this or that behavior, or to interpret outcomes in a probabilistic sense. Issues for which ESD is useful are just too uncertain and complex, and that the ESD models developed are just too wrong for any form of prediction (but also more useful for the purpose of exploration). Hence, ESD may be good as an introduction to dealing with complex and uncertain issues, especially for imagining plausible modes of behavior; it is not useful for detailed analysis in view of detailed implementation or to (totally) reduce uncertainties. ESD modeling is thus most appropriate for quick and dirty modeling if time is at a premium and for assumption based modeling if uncertainties are too deep for traditional approaches.

[1] Counter-intuitive policies in the case of de/radicalization may be (i) less control instead of more, (ii) gradually changing the (entire) population instead of forcing radical groups to change, (iii) to spend resources on perception and expectation management of radical groups.

Although ESD in isolation may be appropriate for some issues and purposes, it may also be insufficiently systematic for well-founded decision support for issues characterised by deep uncertainty. ESD may still be useful for that purpose, but then as a scenario generator for EMA.

2.2 Exploratory modeling and Analysis (EMA)

Exploratory modeling and Analysis (EMA) can be used (i) to explore the influence of uncertainties[2], and (ii) to test the effectiveness and robustness of policies given all these uncertainties.

EMA consists more precisely of (*i*) developing 'exploratory' –fast and relatively simple– models of the issue of interest, (*ii*) generating an ensemble of future worlds (thousands to millions of scenarios) by sweeping uncertainty ranges and varying uncertain structures and boundaries, (*iii*) simulating and analyzing the dynamic behaviors, bifurcations, et cetera, (*iii*) and/or specifying a variety of policy options (preferably adaptive ones), and simulating, calculating, and comparing the performance of the various options across the ensemble of future worlds.

Although data analysis techniques (step (*iii*)) could be used to investigate the effect of underlying mechanisms/(inter)actions/conditions, to separate different modes of behavior, to determine the conditions that lead to these different modes of behaviors, to find bifurcation points and critical variables, it may be even more interesting to define different (adaptive) policies/strategies and immediately test their (relative and absolute) effectiveness/robustness given all these uncertainties (step (iv)). The effectiveness/robustness of policies can then be evaluated over the entire multidimensional uncertainty space without needing to analyze/understand millions of outcomes. In other words, the effectiveness/robustness of policies/strategies could be evaluated and compared without reducing uncertainties related to the system of interest and without getting overwhelmed by combinatorial complexity.

EMA is still under development: researchers of several institutes are currently improving, extending and contributing to EMA theory, EMA methodology, and EMA tools, and are working on a plethora of EMA applications, often in combination with adaptive policymaking[3]. Currently, special attention is paid to the combination of ESD and EMA in order to ease their combined application to deeply uncertain dynamically complex issues.

2.3 Exploratory System Dynamics modeling and Analysis (ESDMA)

In 'Exploratory System Dynamics modeling and Analysis' (ESDMA), the fast and relatively simple models used to generate ensembles of future worlds are more specifically ESD models. Since EMA is appropriate for systematically exploring deep uncertainty and testing the robustness of policies, and ESD models are particularly appropriate for generating plausible behaviors over time, it follows that ESDMA is particularly appropriate for *systematically* exploring and analyzing thousands to millions of plausible dynamic behaviors over time, and for testing the robustness of policies over all these scenarios. As opposed to EMA, ESDMA therefore goes beyond the calculation of end states or static values, which is in fact a very serious difficulty, that can be side-stepped in this paper.

Since EMA is a quantitative uncertainty analysis approach and mainstream SD modeling consists of making quantitative simulation models, it follows that ESDMA is mainly a quantitative multi-method, but which leads –just like traditional SD– to qualitative interpretations, conclusions

[2]related to initial values, parameters, specific variable formulation, generative structures, model formulations, model boundaries, different models, different modeling methods and paradigms, and different preferences and perspectives related to different world-views, and policies

[3]For RAND related EMA work see for example (Bankes 1993; Lempert and Schlesinger 2000), (Lempert, Popper, and Bankes 2003; Lempert, Groves, Popper, and Bankes 2006; Bryant and Lempert 2009). For TUD/RAND work, see (Bankes, Walker, and Kwakkel 2010). For Delft University of Technology related EMA work see (Walker and Marchau 2003; Van der Pas, Agusdinata, Walker, and Marchau 2007; Agusdinata 2008), (Van der Pas, Agusdinata, Walker, and Marchau 2008) (Agusdinata, Van der Pas, Walker, and Marchau 2009) (Pruyt 2010b; Pruyt and Hamarat 2010a; Pruyt and Hamarat 2010b) (Kwakkel, Walker, and Marchau 2010a; Kwakkel, Walker, and Marchau 2010b; Kwakkel and Slinger 2011), and (Pruyt, Kwakkel, Yucel, and Hamarat 2011; Pruyt, Logtens, and Gijsbers 2011; Pruyt 2011a).

and recommendations.

3 The First De/Radicalization Model

The model presented and used in this section is just a combination of micro-hypotheses about de/radicalization. The model is high-level, simple, generic, and most certainly 'wrong'. This model and other formulations of the same issue may however be useful. The model is presented in subsection 3.1 (one may want to skip this relatively dry model description), its behavior is quickly analyzed in subsection 3.2, and it is used for ESDMA in subsection 3.3.

3.1 Model Structure of the First De/Radicalization Model

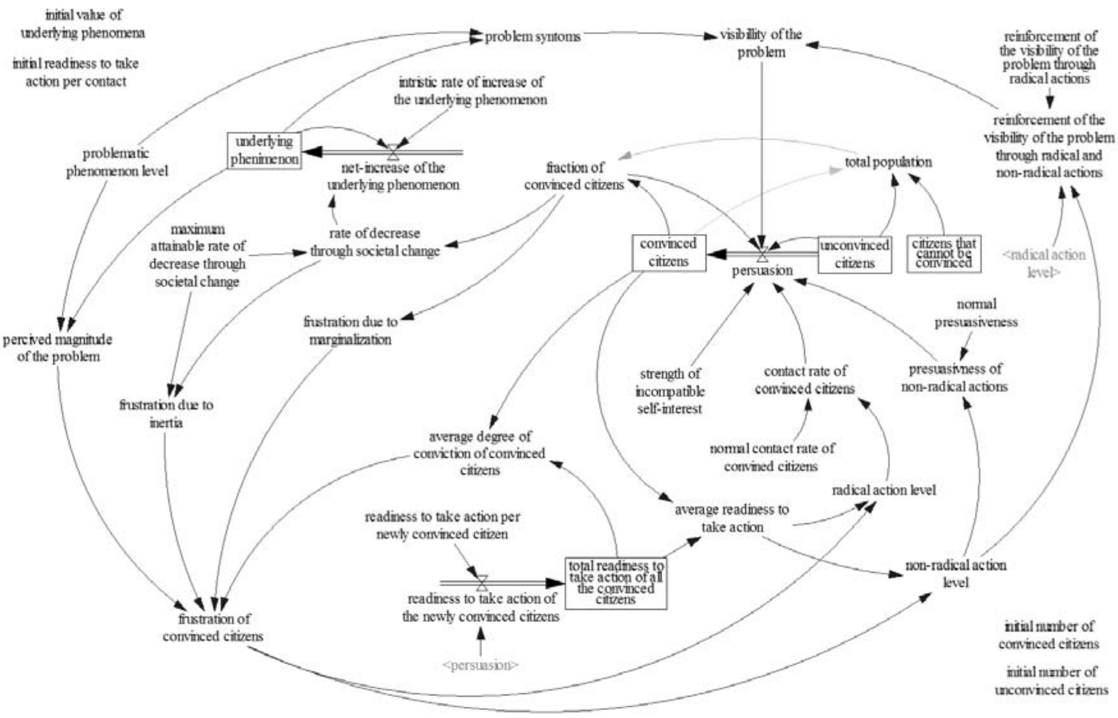


Figure 1: Stock-Flow Diagram of the generic de/radicalization model

In this generic model, it is assumed that radicalization is brought about by a (real or perceived) slumbering underlying phenomenon (see the Stock-Flow structure at the top left of Figure 1). In this version of the model, it is also assumed that problem symptoms become visible when/if the level of the underlying phenomenon increases above a particular level. Here, those problem symptoms are modeled simplistically as the non-negative difference between the underlying phenomenon and the problematic phenomenon level, over the problematic phenomenon level.

But citizens that are convinced of the problem –even if there are no clear problem symptoms visible to the rest of the population yet– perceive the problem: this is modeled here as the fraction of the underlying phenomenon over the problematic phenomenon level. The bigger the perceived problem is, the higher the frustration of those convinced citizens will be. The frustration of convinced citizens –expressed as a percentage between 0% and 100%– is modeled here as the product of the frustration due to marginalization, the frustration due to inertia, the average degree of conviction of convinced citizens, and the perceived magnitude of the problem.

In this model, unconvinced citizens become convinced citizens if/when persuaded by convinced citizens. However, there are also citizens that will never be convinced – they belong to the radicals at the other end of the spectrum. This persuation is modeled here as the product of the contact rate of the convinced citizens, the fraction of convinced citizens, the number of unconvinced citizens, the persuasiveness of non-radical actions, and the visibility of the problem (see below), divided by the strength of their incompatible self-interest. The frustration due to marginalization is a function of the fraction of convinced citizens.

More convinced citizens leads –ceteris paribus– to more societal change. Societal change may allow to stop the increase of, or even decrease, the underlying phenomenon: it is assumed that the rate of decrease through societal change equals the fraction of convinced citizens multiplied by the maximum attainable rate of decrease through societal change. The rate of decrease through societal change mitigates the net increase of the underlying phenomenon. The net increase of the underlying phenomenon is equal to the product of the underlying phenomenon with the difference between the intrinsic rate of increase of the underlying phenomenon and the rate of decrease through societal change.

The difference between the maximal attainable rate of decrease through societal change and the rate of decrease through societal change, divided by the maximum attainable rate of decrease through societal change, is used here as a proxy for the frustration due to inertia – which frustrates convinced citizens if they do not see sufficient change.

In this version of the model, it is assumed that the contact rate of convinced citizens is equal to the normal contact rate of the convinced citizens multiplied by the complement of the radical action level; with the radical action level equal to the average readiness to take action multiplied by the frustration of the convinced citizens.

The non-radical action level is the complement of the frustration of the convinced citizens times the average readiness to take action. The non-radical action level and the normal persuasiveness determine the persuasiveness of non-radical actions. The average readiness to take action equals the total readiness to take action of all convinced citizens divided by the number of convinced citizens.

It is furthermore assumed that the total readiness to take action of all convinced citizens initially equals the product of the number of convinced citizens and an initial readiness to take action per convinced citizen. The total readiness to take action of all convinced citizens increases by means of the flow of persuations multiplied by their readiness to take action – that is, per newly convinced citizens. The average persuasiveness of convinced citizens in this version of the model also equals the total readiness to take action of all convinced citizens divided by the number of convinced citizens.

In the basic version of the model, it is assumed that the visibility of the problem equals the problem symptoms times the reinforcement of the visibility of the problem through radical and non-radical actions, and that the reinforcement of the visibility of the problem through radical and non-radical actions is equal to (1 + *non-radical action level*) ∗ (1 + *radical action level* * *reinforcement of the visibility of the problem through radical actions*).

Figure 2 shows a Causal Loop Diagram of this simulation model – this CLD cannot be aggregated/simplified beyond the one shown here without losing the link between driving structure and behavior.

3.2 Quick and Dirty Exploration of the First De/Radicalization Model

Initial values and parameter values used to generate figures in this subsection are displayed in Table 1.

Figure 3 shows a 'deradicalization' mode of behavior. First, the underlying phenomenon keeps on worsening, causing the frustration of the –at first– small group of convinced citizens to rise, causing them to take radical and non-radical actions, hence, increasing the visibility of the problem –after the first real problem symptoms have become visible– to society at large. The resulting persuasions and drop in frustration (and marginalization) of convinced citizens causes a shift from

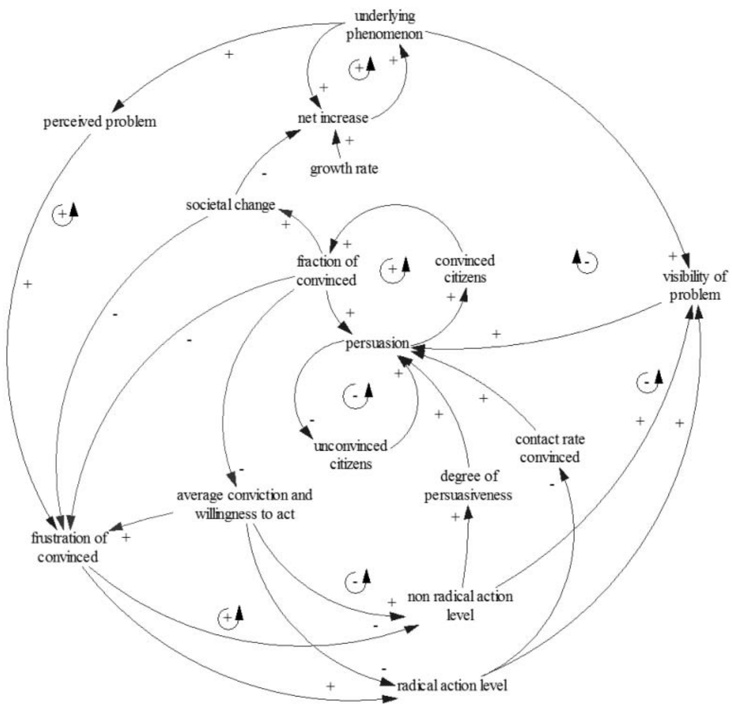


Figure 2: Causal Loop Diagram of the generic de/radicalization model

radical actions to non-radical actions. This shift from radical to non-radical actions increases –at least in this model– the persuasiveness of non-radical actions and de-isolates convinced citizens, allowing for an increase of their contact rate – jointly leading to more persuasions and hence more and more convinced citizens until all citizens –except for the unconvincible, that is, the radical individuals at the other end of the spectrum– are convinced. More and more convinced citizens also means that more and more action is taken to fight the underlying phenomenon until it ceases to be a problem.

Manual univariate sensitivity/uncertainty analysis shows that another mode of behavior could be obtained if –starting from the base case values– one of following changes is made:

- if the initial readiness to take action per convinced citizen –0.8 in the base case– is larger than 0.925;
- if the readiness to take action per newly convinced citizen –0.5 in the base case– is larger than 0.8;
- if the strength of incompatible self-interest –2 in the base case– is larger than 16;
- if the normal contact rate of convinced citizens –1000 in the base case– is smaller than 400;
- if the normal persuasiveness –1% in the base case– is smaller than 0.25%.

Further radicalization –instead of deradicalization– is obtained in all of these cases (see Figure 4(a) for the behavior of the variable frustration of the convinced citizens). Only decreasing the value of the reinforcement parameter does not change the mode of behavior of the model (not displayed). From these quick qnd dirty analyses, it looks as though two radically different modes of behavior can be obtained with this model. Figure 4(b) shows two different scenarios based on these two modes of behaviors.

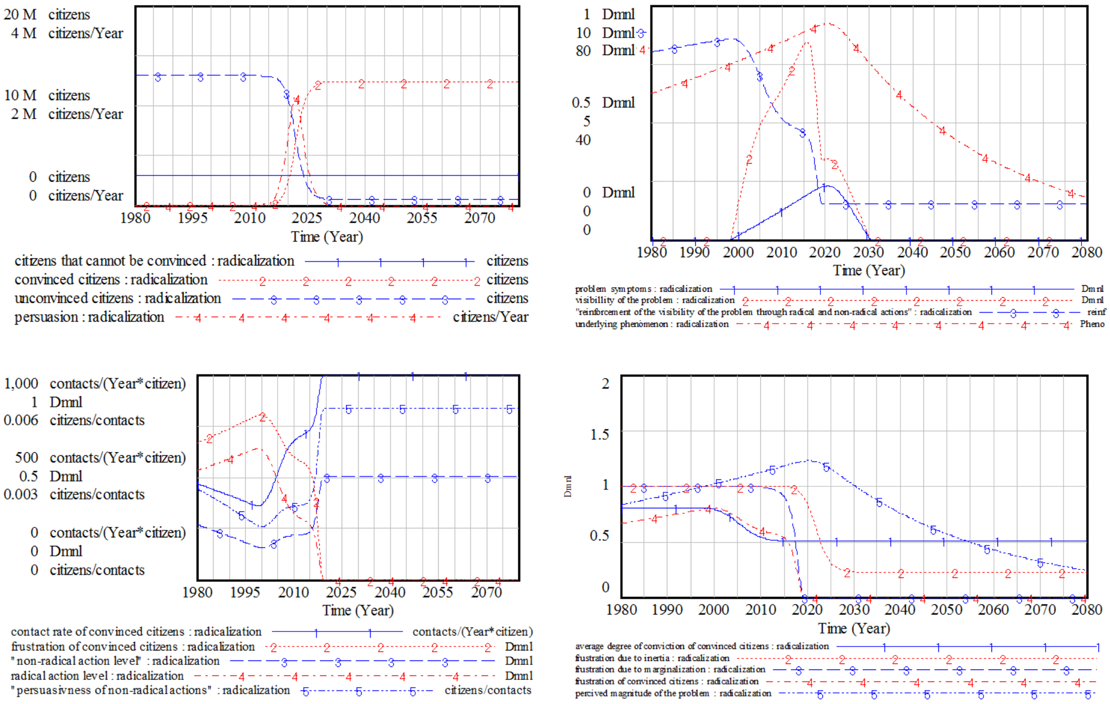
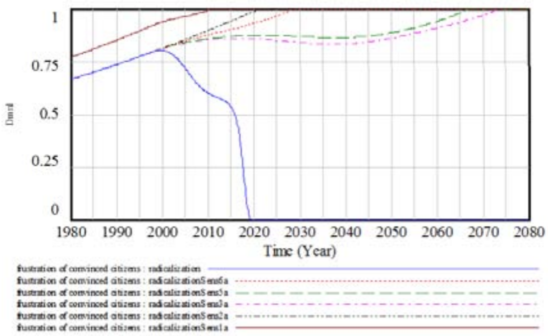
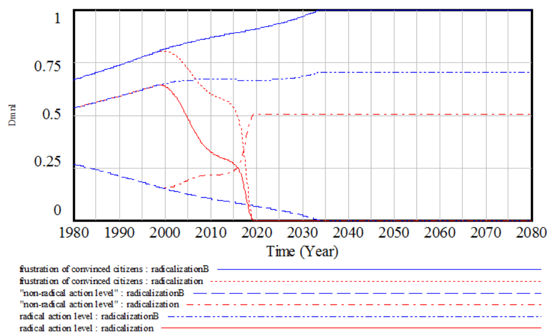


Figure 3: The *de*radicalization mode



(a) Behavior mode sensitivity (*frustration of convinced citizens*) for 5 out of 6 parameters: deradicalization (dark blue) versus radicalization (all other)



(b) Two distinct scenarios: deradicalization (red) versus further radicalization (blue)

Figure 4: *De*radicalization mode versus *radicalization* mode of the de/radicalization model

parameter, initial value, lookup	value(s)	units
underlying phenomenon	50	dmnl
problematic phenomenon level	60	dmnl
initial number of convinced citizens	1.000	citizen
initial number of unconvinced citizens	12.999.000	citizen
initial number of citizens that cannot be convinced	3.000.000	citizen
total population	16.000.000	citizen
maximum attainable rate of decrease through societal change	0.05	1/year
intrinsic rate of increase of the underlying phenomenon	0.01	1/year
normal contact rate of the convinced citizens	1000	contact/person/year
normal persuasiveness	0.01	person/contact
initial readiness to take action per convinced citizen	0.80	dmnl
readiness to take action per newly convinced citizens	0.50	dmnl
reinforcement of the visibility of the problem thr. radical actions	10	dmnl
strength of incompatible self-interest	2	dmnl
frustration due to marginalization	(0, 1), (0.025, 0.50), (0.05, 0.20), (0.075, 0.05), (0.1, 0), (1,0)	

Table 1: Initial values, parameter values and lookup function used in the simulation in Figure 3

3.3 ESDMA of the First De/Radicalization Model

In this case, ESDMA is used for broader and deeper exploration and additional analysis of some parametric uncertainties. Normally ESDMA for policy testing purposes about such a topic would require exploration of model uncertainties, structural uncertainties, etc. However, only this generic model is explored here[4]. This narrow focus allows us to focus here on analysis techniques and visualization techniques for bifurcations.

parameter/initial value	minimum	maximum
normal contact rate convinced	1	2000.0
maximum attainable rate of decrease through societal change	0.01	0.2
problematic phenomenon level	20	100.0
intrinsic rate of increase of the underlying phenomenon	0.005	0.1
strength of the incompatible self-interest	1	20.0
normal persuasiveness	0.001	0.1
readiness to take action per newly convinced citizen	0.2	0.8

Table 2: Parameter values used in the ESDMA

Table 2 contains the parameter ranges used in the ESDMA on this generic model. Figure 5 shows the behaviors of 1000 Latin Hypercube samples for the (a) *perceived or real underlying phenomenon*, (d) the *radical action level*, (c) the *frustration of convinced citizens*, and (d) the number of *convinced citizens*. Although 1000 samples is a rather small set, it allows to show the same patterns without much distortion. Often more samples are better. But in this case, too many samples may result in a distorted picture of the scenario space. The end state histograms of these variables show that non-white space does not necessarily mean many runs. Three of these end state distributions indicate a clear bifurcation in the uncertainty space. In this case, it means that two typical modes of behaviors are generated.

Although the set of behaviors is clearly bifurcated, it is not clear which combinations of values for these uncertainties lead to one or the other outcome. Classification and regression trees allow finding combinations of values splitting the data set: the tree in Figure 6 has been created using the C4.5 algorithm (Quinlan 1993) on an ensemble of 1000 scenarios, with the constraints that minimally 80% of a class needs to belong to one or the other end state and that the minimum subset sizes need to exceed 20 else they are pruned.

[4] We use a case based development strategy to extend our ESDMA toolkit.

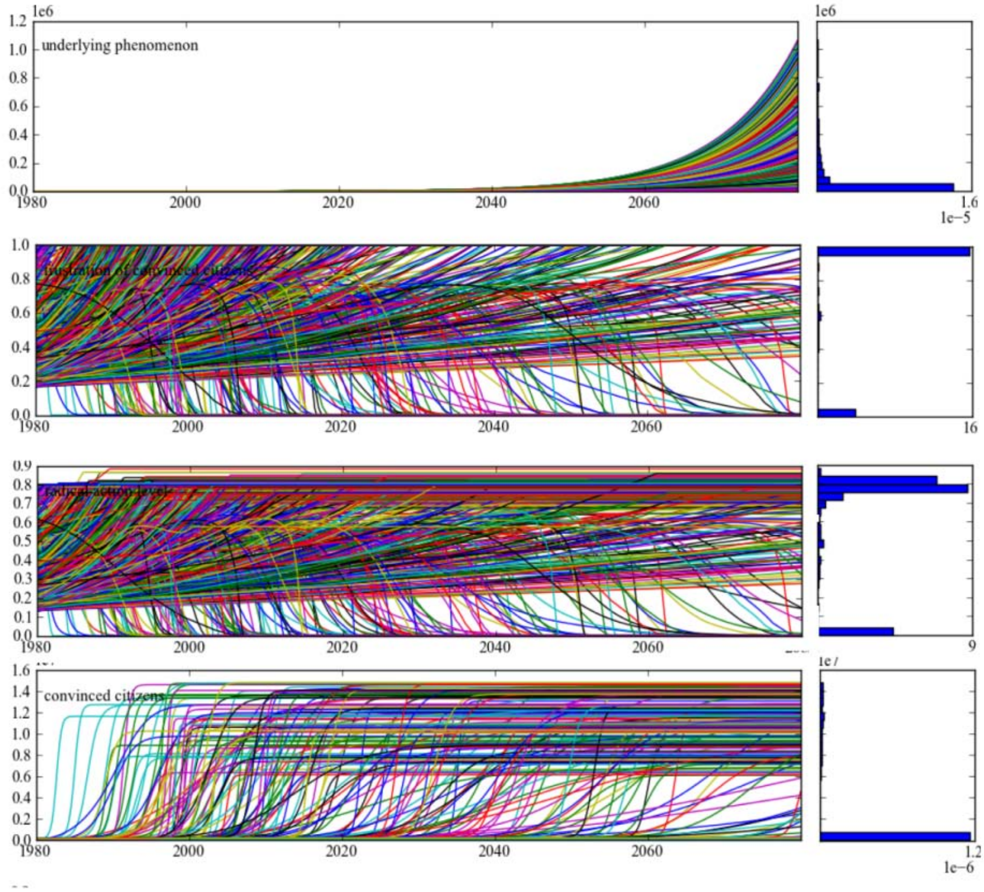


Figure 5: Behaviors of LH 1000 samples for following variables (top to bottom): (a) perceived or real underlying phenomenon, (b) the frustration of convinced citizens, (c) the radical action level, and (d) the convinced citizens

This tree is fairly simple to read and interpret. For example, 269 out of 1000 scenarios had a problematic phenomenon level of less than 41.524 and 269 out of those 269 cases lead to radicalization (=0), not to deradicalization (=1). Out of the remaining 731 scenarios with a problematic phenomenon level of more than 41.524, 28 had a normal persuasiveness of less than 0.005. None of these 28 cases lead to deradicalization. From the remaining 703 scenarios (= 1000 - 269 - 28), 63 had a normal contact rate of convinced citizens of less than 185 person/person/year. In 59 cases out of these 63 low contact rate cases result in further radicalization. And so on.

Reading this three the other way around, we find two more subsets that mostly lead to further radicalization: scenarios characterized by rather high intrinsic rates of increase of the underlying phenomenon – either above 0.027, or above 0.02 in combination with a strong incompatible self-interest (>3.983) and a moderate normal persuasiveness ($0.005 < \ldots \leq 0.033$). All other subsets result in most cases in *de*radicalization.

At this point we should warn against probabilistic interpretation (e.g. 269/1000 or 26.9%) and/or attaching too much value to the 'discrete splits' (e.g. a problematic phenomenon level of 41.524) and even to the identified subsets: given deeply uncertain and dynamic issues and exploratory model(s) thereof, classification trees could be used in ESDMA to identify key uncertainties and to get a rough idea of specific subspaces. Trees generated with slightly different settings may already lead to different trees. Analyzing (a set of) trees –aka random forests– may nevertheless provide useful information for further explorations (e.g. directed searches) and for designing adaptive policies and associated dynamic monitoring mechanisms.

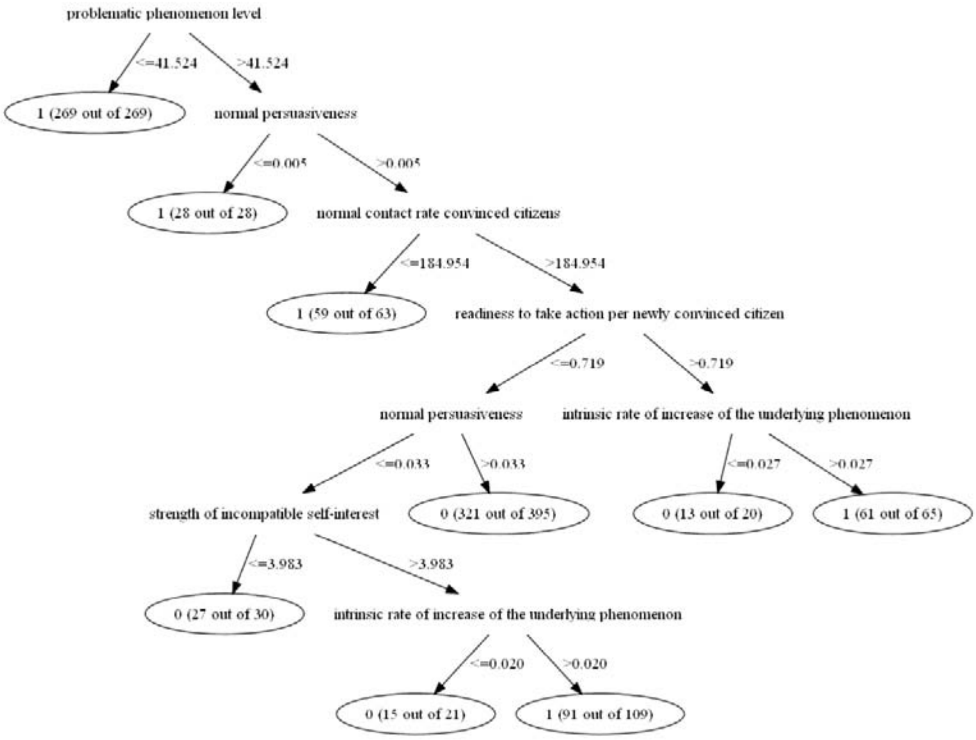


Figure 6: Classification tree: 1 = radicalization ; 0 = deradicalization

The two different modes are also clearly distinguishable in the 4D-plot in Figure 7 (1000 scenarios). Following four variables are rescaled between 0 and 10 and plotted: the perceived or real underlying phenomenon, the number of convinced citizens, the frustration of those convinced citizens, and the radical action level (in color). This 4D-plot shows that –with this version of the model and with these uncertainties– two opposite end states are reached: one end state consists of many convinced citizens who deal with the underlying phenomenon and, hence, their frustrations – the other end state consists of few highly frustrated and 'isolated' individuals who are unable to convince others –with more radical actions– and, hence, are unable to deal with the underlying phenomenon.

Time series clustering on the *underlying phenomenon* with a simplistic Atomic Behavior Pattern concatenation and classification algorithm on these 10000 runs leads to 15 clusters of respectively 8505, 640, 512, 111, 69, 36, 32, 31, 22, 21, 9, 7, 3, 1, and 1 runs (see Figure 8 for eight interesting clusters).

3.4 Conclusions Related to the First De/Radicalization Model

The model presented and used above is just one among many different models about deradicalization and radicalization. This particular model leads to counter-intuitive policy recommendations: it is implicitly assumed that isolation leads to radicalization, hence, the advice in view of deradicalization would be to integrate radical groups/individuals or to manage society at large through a transition process towards the good aspects of (some) ideas shared by (potential) radical individuals/groups. Moreover, this model is generic: it could be tailor-made for specific situations but does not –in its current form– fit any situation in particular. Hence, it does not have any predictive value for specific real-world de/radicalization processes. But even then is it useful for several reasons:

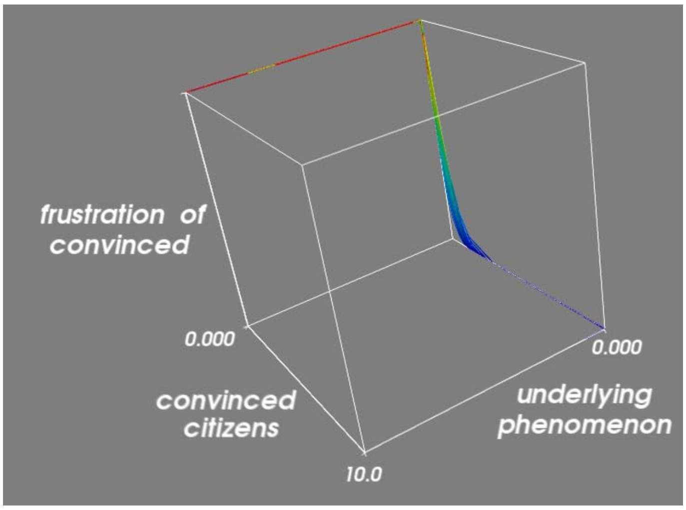
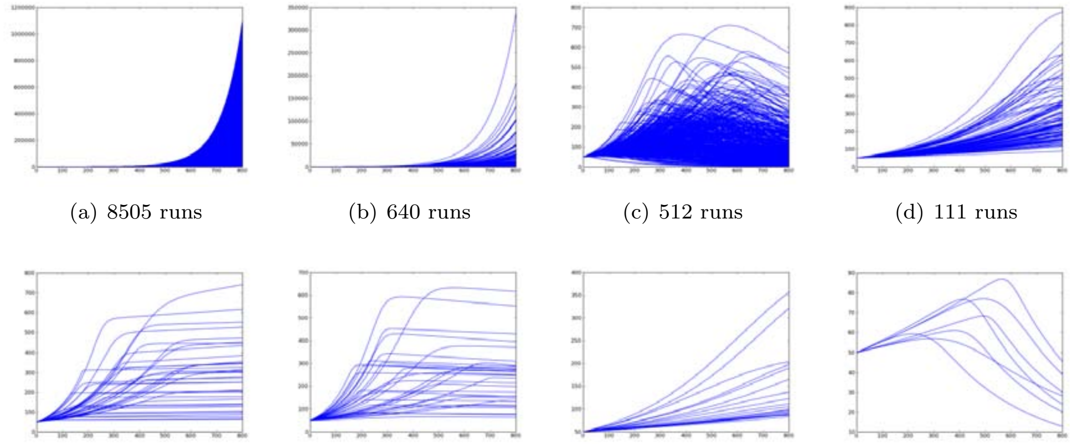


Figure 7: 4D-plot (3 spatial dimensions + 1 color dimension) of 1000 runs

- The model is –from a methodological point of view– an interesting toy model for developing and testing ESDMA analysis techniques and visualization tools for cases characterized by bifurcations (see above): in this particular case, classifying the end states means classifying the modes of behaviors, not necessarily the root causes (uncertainties) – classifying modes of behavior under deeply uncertain dynamic complexity is much more difficult[5].
- The model is –from an applied point of view– an interesting starting point for developing rather different exploratory models about specific de/radicalization processes;
- The model is –from an educational point of view– an interesting model for illustrating how one and the same endogenous model can generate a few different –almost opposite– modes of behavior.

[5]Classification algorithms for more complex cases (in terms of modes of behaviors) are currently under development in our research lab.



(a) 8505 runs (b) 640 runs (c) 512 runs (d) 111 runs

(e) 36 runs (f) 31 runs (g) 21 runs (h) 7 runs

Figure 8: Different clusters generated for the behavior of the underlying phenomenon with a simplistic Atomic Behavior Pattern concatenation and classification algorithm

4 The Second De/Radicalization Model

The model presented and used in this section is another combination of micro-hypotheses about de/radicalization – similar to the previous model, but different enough to be called a different model. The model is also high-level, simple, generic, and 'wrong', but may be useful. The model is presented in subsection 4.1 and used for ESDMA in subsection 4.2.

4.1 Model Structure of the Second De/Radicalization Model

Changing the previous generic model slightly already leads to a new de/radicalization model (see Figure 9). Additional structures were added (part of the variables in red) to distinguish activists from extremists from terrorists (AIVD 2010). They influence the system in different ways. 0ther functions and structures were changed too (the other part of the variables in red).

4.2 ESDMA of the Second De/Radicalization Model

Figure 10 shows the outputs of 1000 simulations with this model for the parametric uncertainties discussed above (as well as uncertainty ranges on the initial values of the subpopulations in the model). The graphs of the individual traces seem to suggest that the results of the end states are more or less evenly spread over the range. The corresponding envelopes and distributions tell a slightly different story, especially for homegrown extremists and homegrown terrorists, namely that the full spectrum is plausible, but not likely. Different cuts would allow the exploration of the development over time. Again it should be stated that *(i)* quantitative interpretation of probability distributions or histograms is irrelevant from an EMA point of view – plausibility is what matters, and *(ii)* only some parametric uncertainties are explored here using a simplistic toy model – real analysis requires at least the consideration of structural and model uncertainties too. Direct searches in and analysis applied to the ensemble of scenarios may help to explore causes of the low-probability high-risk cases and may suggest potential solutions.

But here it suffices to note that the ensemble of behaviors generated by this model and these uncertainties is plausible and that it differs from the ensemble generated with the first model – remember: diversity is good.

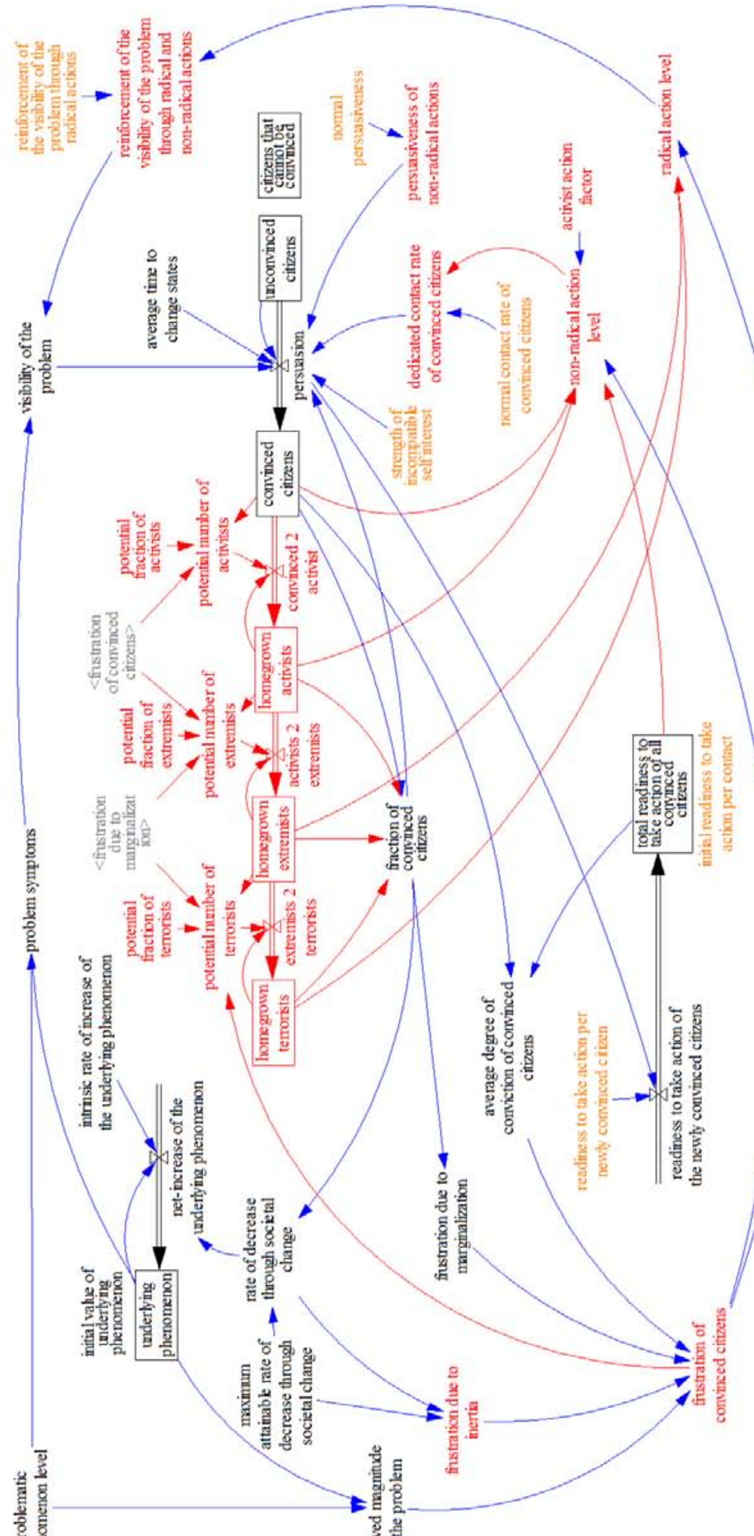


Figure 9: Stock Flow Diagram of an alternative De/Radicalization model

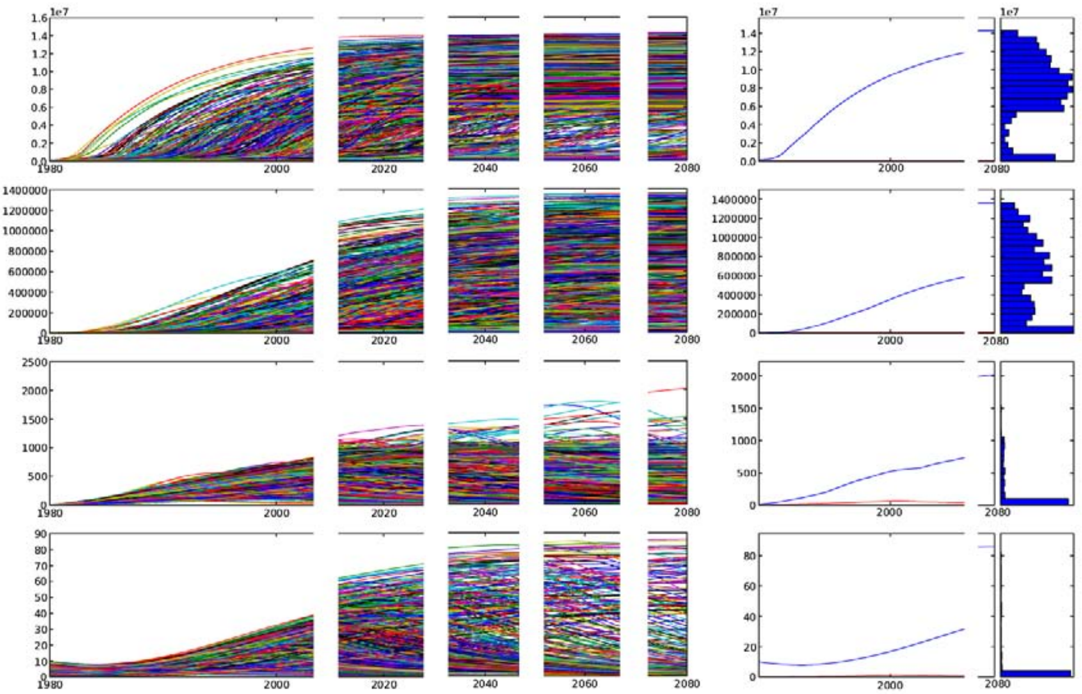


Figure 10: Individual traces LH1000 (left) and the corresponding envelopes and end state distributions for the second SD model for following variables (from top to bottom): convinced citizens, homegrown activists, homegrown extremists, and homegrown terrorists

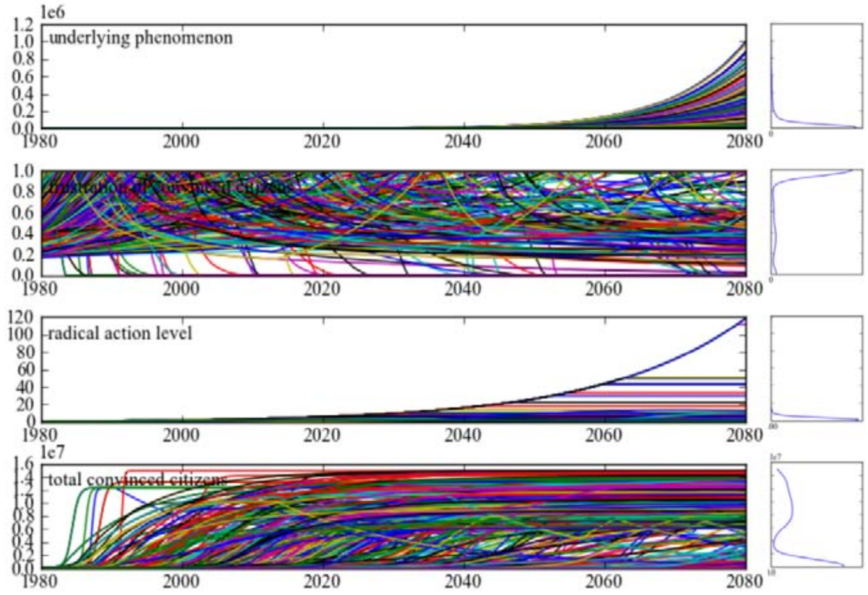
5 ESDMA on 2 x 2 Models

Both models discussed above as well as two structural variants (the two models with return flows from convinced citizens to unconvinced citizens) are used in this section as an illustration of an ESDMA with multiple models. The different models should, in real-world multi-model ESDMAs, be plausible and also as divers as possible – which is not the case in this illustration. Only the core set of uncertainties should be shared (model specific uncertainties can be dealt with too).

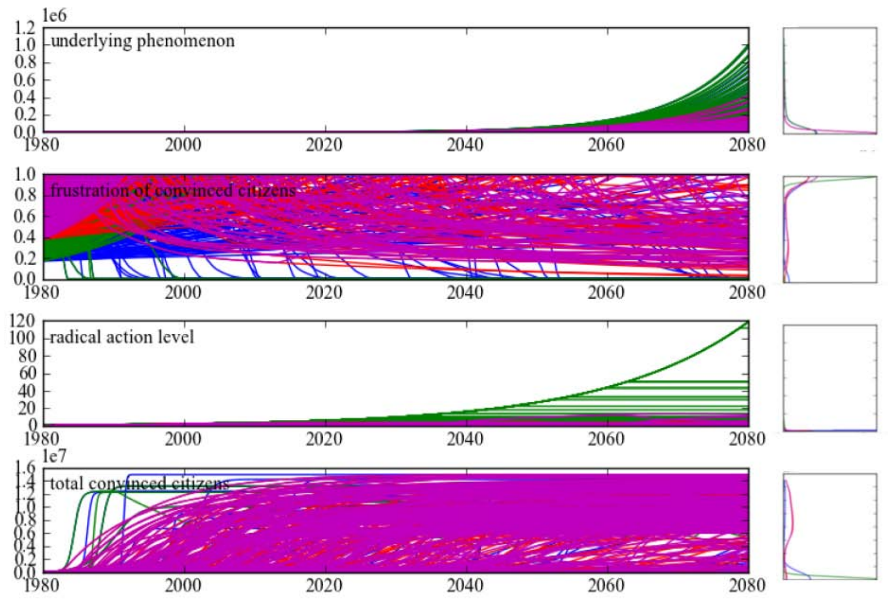
In a real-world ESDMA, models should not be pre-analyzed in detail as in subsection 3.3. Testing the plausibility of behavior –as in subsection 4.2– is recommended though. The reason for not performing detailed analysis on each of the models' output relates to the aim of ESDMA: to generate an ensemble of –ideally all– plausible behaviors and to analyze the ensemble as a whole. Moreover, real-world EMA should also include models that are used in the field but are black-box models (e.g. undisclosed for proprietary reasons or black-box models from a technical point of view). Ex-post, that is to say, during the analysis phase, time-series clustering and classification may still show that a particular type of behavior is only generated by a particular model or structure, although that is not guaranteed. Subsection 3.3 does not make much sense from an ESDMA point of view – it does from a SD point of view and an educational point of view (first uni-model ESDMA before multi-model ESDMA).

5.1 The Ensemble of Scenarios

Figure 11 displays 1000 individual runs generated with the same experimental design (Latin Hypercube) uniformly changing the 12 uncertainties displayed in Table 3 for each of the four different models (thus, simulating each model 250 times). Figure 11(b) shows the same runs, but in a different color for each of the four models, both for envelopes and lines.



(a) lines for all models (no distinction)



(b) lines color-coded for each of the models

Figure 11: Lines and kernel density estimates without distinction between the models (left) and with distinction between the different models (right)

parameter/initial value	minimum	maximum
normal contact rate of convinced citizens	1	3650
maximum attainable rate of decrease through societal change	0.001	0.1
problematic phenomenon level	20	200
intrinsic rate of increase of the underlying phenomenon	0.005	0.1
strength of incompatible self interest	0.8	20
normal persuasiveness	0.0001	0.01
readiness to take action per newly convinced citizen	0	1
initial number of convinced citizens	50000	150000
initial number of activists	500	1500
initial number of extremists	0	10
initial number of terrorists	0	10
citizens that cannot be convinced	1000000	10000000

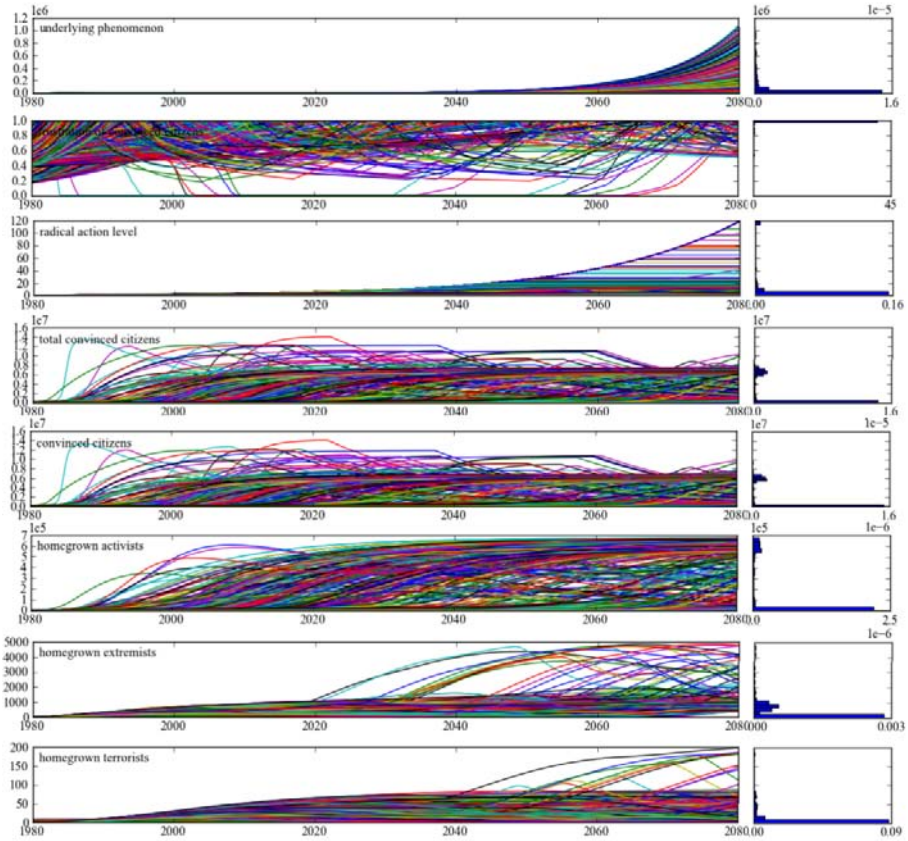
Table 3: 12 random uniformly sampled uncertainties (Latin Hypercube) and the corresponding uncertainty ranges

parameter/initial value	minimum	maximum
normal contact rate of convinced citizens	365	3650
maximum attainable rate of decrease through societal change	0.01	0.1
normal contact rate of convinced citizens	365	3650
maximum attainable rate of decrease through societal change	0.01	0.1
intrinsic rate of increase of the underlying phenomenon	0.005	0.1
normal persuasiveness	0.0001	0.01
readiness to take action per newly convinced citizen	0	1
citizens that cannot be convinced	1000000	10000000

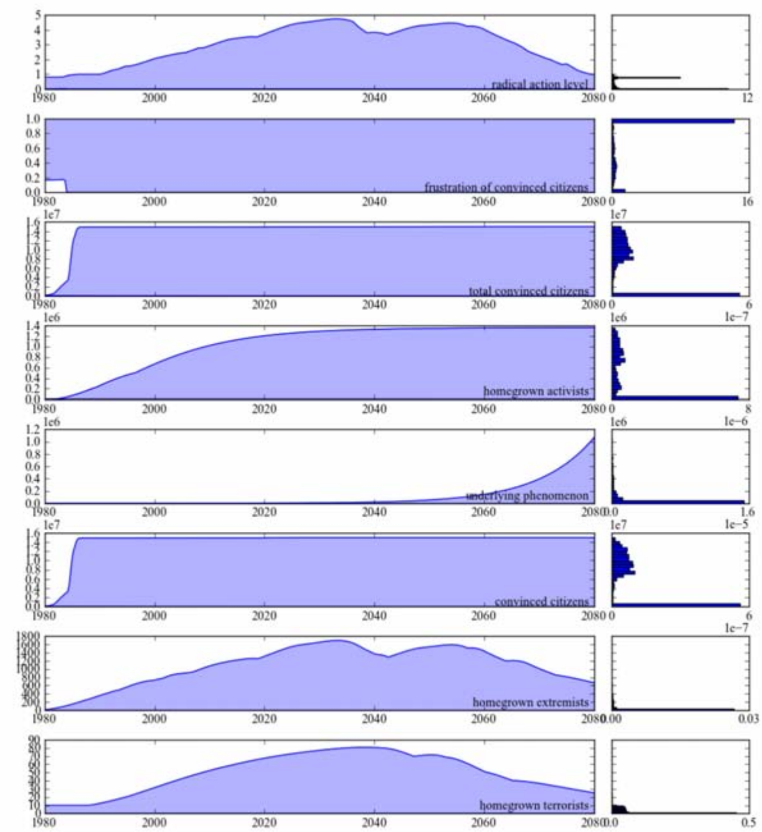
Table 4: 8 random uniformly sampled uncertainties (full factorial) and the corresponding uncertainty ranges from which 4 values are sampled

A Full Factorial (FF) design may be needed to control the experimental design and perform particular analysis. Starting with the same type of analysis as in the LH simulations helps to appreciate differences and similarities between the designs for the case at hand. Applying a full factorial design to each of these 4 models with 4 values per uncertainty for the uncertainties listed in Table 3 leads to 16384 runs. Figure 12 shows 1190 out of 16384 full factorial runs with end states for *radical action level* (RAL) above 1, and the remainder of the runs with a RAL end state value below 1. Concatenation and time-series clustering of this ensemble already leads to 16 clusters for the subset with RALs above 1.

One type of analysis and visualization for which a Full Factorial (FF) design is (currently) needed is robustness analysis based on relative regret. Normally one would want to use that type of analysis to compare different policies over the entire uncertainty space. With different models (and without different policies) this type of analysis could also be used to detect which model performs worst in parts of the uncertainty space. Figure 13 shows the performance on a single key output indicator (the *radical action level*) for all FF uncertainties, visualized for two uncertainties (the *normal contact rate of convinced citizens* between 365 and 3650 and the *maximum attainable rate of decrease through societal change* between 0.01 and 0.1 (white = zero regret, which is desirable – for more information about this type of analysis and visualization, see (Lempert, Popper, and Bankes 2003)). These graphs indicate that the first model does not perform well for a below-average *maximum attainable rate of decrease through societal change* and that the behavior of the other models mainly differs in terms of the *normal contact rate of convinced citizens*, with the second model performing badly in the lower range, and the other two models performing badly in the higher range of the *normal contact rate of convinced citizens*. These results could be used to develop policies to remedy worst performance.



(a) 1190 out of 16384 with *radical action level* end states above 1



(b) rest of the runs with *radical action level* end states below 1

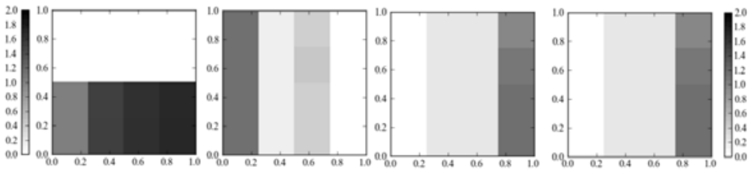


Figure 13: Visualization of the relative regret for the radical action level for the same Full Factorial design applied to each of the four models (white is no regret which is preferable)

6 Conclusions

Although Exploratory System Dynamics Modeling and Analysis is a model-based methodology, it actually requires a mental switch from traditional modelers. In ESDMA, there is no single base case: all plausible cases are base cases.

The main uses of ESDMA are exploration to broaden the horizon and testing of deep robustness. If it reverts to prediction at all, then only to 'ensemble prediction of (modes of) behaviors' over the entire uncertainty space and claims about 'policy robustness'. It starts and ends with uncertainties. And the design of adaptive policies and resilient systems that lead to robust behavior/outcomes are pursued.

ESDMA greatly enhances SD. ESDMA is currently under rapid development in our ESDMA lab. New versions of the software are continuously developed (the preliminary version of this paper was developed using version 1.0 –a single model version– and the final version using version 2.1 –a multi-model version– and version 3.0 –a multi-model multi-policy version– will be implemented soon) and many algorithms are under development, from time series classification algorithm (System Dynamicist surely understand that the analysis of end-state is insufficient) to powerful interactive data visualization algorithms.

This paper shows the application of ESDMA to radicalization versus deradicalization. However, that is not the real issue addressed in this paper. The main issue addressed is methodological (almost philosophical): current computing power allows to deal with deep uncertainty and dynamic complexity. And if we can, then we should. The specific point made in this paper is the need for multi-model exploration to deal with structural and model uncertainty.

The application domain is of course interesting too: some simplistic versions of all plausible models about de/radicalization and activism were presented and (jointly) analyzed. These simple models generate fascinating dynamics. The de/radicalization cases dealt with in this paper are –from an applied decision support point of view – just toy cases.

The first model illustrated both ESD and ESDMA for cases characterized by bifurcations. The other models showed different ensemble behaviors – nevertheless all plausible. Multiple models should preferably be used in ESDMA since the set of all plausible behaviors –aimed for in ESDMA– cannot be generated with just one model. The models considered in this paper are from that point of view too similar: in reality, a much wider model diversity should be aimed for.

The uncertainties dealt with in this paper included parametric uncertainties, but also different models. Not dealt with were uncertainties related to functions and formulations, generative structures, loops, and submodels within one and the same model, different model formulations and model boundaries, and hence, different world-views (and hence, different models and preference systems, and different modeling methods and paradigms). Real-world ESDMA of de/radicalization would also require the consideration of structural, uncertainties, model uncertainties, different world-views, etc. Only then would the ESDMA be sufficiently broad for testing the robustness of adaptive policies (the effectiveness of policies over the ensemble of scenarios).

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A Teaching and Testing Cases

The case description of one of two hot teaching/testing –in line with other teaching/testing published in (Pruyt 2011b), (Pruyt 2010a) and (Pruyt 2009)– the one corresponding to the first model used in this paper, is available in this appendix. The second model is only available to SD lecturers upon request.

Case Description: The De/Radicalization Case I (/25)

A new international research institute dedicated to security and terrorism has recently been founded in The Hague. The institute asks you to make a generic, explorative SD simulation model related to (de) radicalization (that could at a later stage be used to study animal rights activism, climate terrorism, etc). From discussions with leading security experts, you learn that:

Radicalization is often brought about by a (real or perceived) slumbering *underlying phenomenon.* Suppose for example that this *underlying phenomenon* initially equals 50 and increases (or decreases) through a *net-increase of the underlying phenomenon. Problem symptoms* become visible when/if the level of this *underlying phenomenon* increases above a *problematic phenomenon level* of, say, 60. These problem symptoms could be modeled simplistically as the difference between the *underlying phenomenon* and the *problematic phenomenon level*, divided by the *problematic phenomenon level. Problem symptoms* can (mathematically speaking) only be non-negative.

But even if there are no *problem symptoms* yet, there is –for *convinced citizens*– a *perceived magnitude of the problem*, equal to the *underlying phenomenon* divided by the *problematic phenomenon level.* The higher the *perceived magnitude of the problem* is, the higher the *frustration of the convinced citizens* will be. Security experts suggest to model the *frustration of the convinced citizens* as a percentage between 0% and 100%, equal to the product of the *frustration due to marginalization*, the *frustration due to inertia*, the *average degree of conviction of the convinced citizens*, and the *perceived magnitude of the problem.*

Unconvinced citizens could become *convinced citizens* if they are persuaded by already *convinced citizens.* However, there are also *citizens that will never be convinced.* Suppose that the initial number of *convinced citizens* equals 1.000, the initial number of *unconvinced citizens* equals 12.999.000 and that the initial number of *citizens that cannot be convinced* equals 3.000.000 – on a total population of 16.000.000 citizens. The *convinced citizens* could for example be modeled as the product of the *contact rate of the convinced citizens*, the *fraction of convinced citizens*, the *unconvinced citizens*, the *persuasiveness of non-radical actions*, and the *visibility of the problem* (see last paragraph), divided by the *strength of incompatible self-interest.* The *fraction of convinced citizens* equals of course the number of *convinced citizens* divided by the sum of all citizens.

Suppose for a start that: if the *fraction of convinced citizens* equals 0 then the *frustration due to marginalization* equals 100%, if the fraction equals 0.025 then the *frustration due to marginalization* equals 50%, if the fraction equals 0.05 then the *frustration due to marginalization* equals 20%, if the fraction equals 0.075 then the *frustration due to marginalization* equals 5%, and that if the fraction is equal or greater than 0.1, the *frustration due to marginalization* equals 0%.

More *convinced citizens* implies that more societal change may be expected. Societal change may allow to stop the increase of, or even decrease, the underlying phenomenon: assume that the *rate of decrease through societal change* equals the *fraction of convinced citizens* multiplied by the *maximum attainable rate of decrease through societal change* of for example 5% per year. This *rate of decrease through societal change* mitigates the *net increase of the underlying phenomenon.* This *net increase of the underlying phenomenon* equals the product of the *underlying phenomenon* with the difference between the *intrinsic rate of increase of the underlying phenomenon* and the *rate of decrease through societal change.* Suppose in this generic model that the *intrinsic rate of increase of the underlying phenomenon* is equal to 1% per year.

The difference between the *maximal attainable rate of decrease through societal change* and the *rate of decrease through societal change*, divided by the *maximum attainable rate of decrease* *through societal change*, can be used as a proxy for the *frustration due to inertia* which frustrates the convinced citizens if they do not see sufficient change.

Suppose that the *contact rate of the convinced citizens* equals the *normal contact rate of the convinced citizens* of, say, 1000 (different and sufficiently close) contacts per person per year multiplied (100% - *radical action level*); with the *radical action level* equal to the *average readiness to take action* multiplied by the *frustration of the convinced citizens*.

The *non-radical action level* is the complement of the *radical action level*, in other words (100% - *frustration of the convinced citizens*) ∗ *average readiness to take action*. The *non-radical action level* and the *normal persuasiveness* of 0.01 persons per contact determine the *persuasiveness of non-radical actions*. The *average readiness to take action* equals the *total readiness to take action of all the convinced citizens* divided by the number of *convinced citizens*.

Suppose that the *total readiness to take action of all the convinced citizens* initially equals the product of the number of *convinced citizens* and an *initial readiness to take action per convinced citizen* of, say, 80%. The *total readiness to take action of all the convinced citizens* increases through adding *readiness to take action of the newly convinced citizens*, equal to the flow of the *newly convinced citizens* multiplied by the *readiness to take action per newly convinced citizens* of, say, 50%. The *average persuasiveness of the convinced citizens* also equals the *total readiness to take action of all the convinced citizens* divided by the number of *convinced citizens*.

Suppose, for now, that the *visibility of the problem* is equal to the *problem symptoms* times the *reinforcement of the visibility of the problem through radical and non-radical actions*, and that the *reinforcement of the visibility of the problem through radical and non-radical actions* is equal to (1 + *non-radical action level*) ∗ (1 + *radical action level* * *reinforcement of the visibility of the problem through radical actions*). Set the *reinforcement of the visibility of the problem through radical actions* equal to 10, and the *strength of incompatible self-interest* to 2.

1. (/10) Model this issue. Verify and simulate the model over a time horizon of 100 years, starting in 1980.
2. (/1) Make graphs of the *convinced citizens* and the dynamic factors that directly influence the *newly convinced citizens*.
3. (/2) Validate the model: describe and perform 2 different validation tests (except sensitivity analysis – see the next question) and the conclusions of these tests. What would/should be the goal of validation in this explorative case?
4. (/3) Test the sensitivity of the model for changes in following parameters: the *initial readiness to take action per convinced citizen*, the *readiness to take action per newly convinced citizens*, the *strength of incompatible self-interest*, the *reinforcement of the visibility through radical actions*, the *normal contact rate of the convinced citizens*, and the *normal persuasiveness*. Briefly describe your conclusions.
5. (/3) Make two interesting and consistent exploratory scenarios. Simulate the scenarios and save the outputs (graphs). What could be concluded from those exploratory scenarios?
6. (/2) Make a strongly aggregated CLD of this simulation model. And use the CLD to explain the link between structure and behavior.
7. (/2) Formulate policy advice –based on this modeling exercise– related to ***de***radicalization.
8. (/1) Give examples of 2 'soft variables' in this model. Why could they be called 'soft'?
9. (/1) This is of course a preliminary generic model, and the analysis is explorative at best. Give advice related to future refinements and extensions. How do you think those refinements and extensions would change the model behavior?