Chapter 7

Developing Agent-Based Simulation Models for Social Systems Engineering Studies: A Novel Framework and its Application to Modelling Peacebuilding Activities

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Abstract

When looking for a "what-if" analysis tool to support social systems engineering studies, agent-based modelling and simulation should be the method of choice. It is a well-established method for studying human-centric systems. Developing such models, however, is not an easy task, and there is not much guidance around, that clearly explains how this is done. In this book chapter we present a novel framework to guide teams through the process of model development from conceptual design to implementation. While we describe the tools that can be used for this purpose we also provide guidance on how the required information can be produced. We borrow ideas from software engineering to define a more structured approach to problem analysis and model design. We use an illustrative example (international peacebuilding activities in South Sudan) to demonstrate how the novel framework has been applied in a real world setting. This illustrative example confirms that a structured approach is very helpful when dealing with a multidisciplinary team and a case-based project.

Keywords:

Agent based modelling, social simulation, social systems engineering, software engineering, multidisciplinary team, peacebuilding, South Sudan

7.1 Introduction

Agent-Based Modelling and Simulation (ABMS) is a well-established method for studying human-centric systems and is therefore well suited for supporting the investigation of different scenarios related to Social Systems Engineering. An example of Social Systems Engineering opportunities where ABMS could be applied to evaluate different strategies is that of peacebuilding efforts to bring peace and stability to conflict-affected countries. But how do we develop such a model? What are the steps required for model conceptualisation, design, and implementation? We found ourselves left alone with these kinds of questions when we aimed to build a simulation model to study the impact of current international peacebuilding efforts in conflict areas such as South Sudan. After many focus group meetings and discussions within our multidisciplinary team we derived a framework to develop such models in a more formal way.

In this chapter we introduce the framework as a tool that employs the possibilities of computer modelling and simulation for advancing the way in which peacebuilding processes can be better understood and improved, given the complexity that social systems represent. The aim is to assist advancing prospects towards Social Systems Engineering in two manners: (i) by presenting a guide to model, re-use and extend ABMS systems and (ii) to employ the obtained simulation models as decision-support tools to investigate the result of applying public policies, actions and interventions to promote societal changes.

Our work represents the outcome of a study bringing together computer scientists, psychologists, political and sociological researchers into the development of a framework to facilitate model design, social engineering and decision-making for peacebuilding. The approach focuses on applying Software Engineering techniques in agent based social simulation to describe factors that would trigger individuals' actions/responses to their environment. We establish a framework that integrates individual stakeholders within the social scenario, with their physical and psychological properties embedded within agents. The initial goals are (i) to advance modelling and understanding of real-world peacebuilding scenarios using a graphical notation for agent-based simulation modelling; and (ii) to produce a re-usable toolkit to assist in peacebuilding and other social simulation exercises. In addition, we establish a less restrained, intuitive manner of incorporating theories of human behaviour into social simulation models. We therefore introduce our framework as a new intervention tool to assist researchers from different research communities who are interested in Social Systems Engineering, to investigate "what-if" scenarios, as well as assess the plausibility of activities and solutions in social simulation contexts.

Software Engineering techniques can enable stakeholders from different communities (within research and society) to communicate their ideas in a structured manner. Using a graphical notation, such as the Unified Modelling Language (UML) or System Modelling Language (SysML) has several advantages within a multidisciplinary context: (i) it is easy to communicate and unambiguous; (ii) it is robust as the complexity of the system being modelled increases; (iii) it is easily adaptable/extensible to new system requirements; (iv) it allows reusability and it is of easy maintenance; (v) it allows hierarchical modelling; (vi) the final implementation decisions of the system can be delayed, as the refinement of functionalities is defined during the design phases; (vi) it allows for automated implementation (at least to a certain degree); and (vii) it is ideal for modelling within groups of people, as it requires several iterations for the characterisation of system requisites. In addition, the iterative process as to how the documentation is produced allows social scientists to better understand the model as well as the final simulation system. This framework aids researchers to scrutinise the real world and subsequently pinpoint useful inputs and abstractions for the simulation system.

In the remainder of this chapter, we provide some background information regarding simulation and peacebuilding, before we explain the steps of the framework and exemplify how to employ it for social systems engineering studies through an illustrative example. This example investigates the perceptions and behaviours of the South Sudanese people towards peacebuilding efforts. Through simulation experiments with the model we show how changes in internal and external peacebuilding policies affect the behaviour of individuals and impact the dynamics of the population.

7.2 Background

7.2.1 Simulation

A computational simulation of a dynamic system can be defined as an "imitation (on a computer) of a system as it progresses through time'' (Robinson 2004). The model user determines the possible scenarios to be investigated and the simulation predicts the outcomes. Simulation can, therefore, also be seen as a decision support tool. The purpose of simulation is to understand, change, manage and control reality (Pidd 1992). Moreover, simulation can be used to obtain a better understanding and/or to identify improvements to a system (Robinson 2004). Simulation models are focused on the main aspects of the real system; they are therefore a simplified version that excludes unnecessary details of the original system.

ABMS is a modelling and simulation approach largely employed in the field of Social Simulation due its characteristics and capabilities. It is a technique that employs autonomous agents that interact with each other (Macal and North 2005). The agents' behaviour is described by rules that determine how they learn, respond to the environment, collaborate with each other and adapt. The overall system behaviour arises from the agents' individual dynamics and their interactions (Siebers and Aickelin 2007). For social simulation, it can amalgamate real-world data on distinct interactions between individuals in society an impression of the system as a whole.

There is no consensus about a definition of an agent among the ABMS community. Macal and North (2005) defines some characteristics for an agent:

- A self-contained, modular, and uniquely identifiable individual. An agent has a set of attributes, the values of which will define it as a unique individual in the system.
- They are situated in an environment where the interactions with other agents occur. Agents are capable to respond to the environment and have protocols to communicate with other agents. Their responses to environmental stimulus and interactions are defined by rules that determine their reactive and proactive behaviours. Apart from behavioural rules, agents communicate with each other through message exchange.
- Agents are autonomous and self-directed.
- Agents are flexible, with the ability to learn and adapt their behaviours according to the environment and past experiences, and they also can have memory.
- They are goal-directed, having objectives to achieve determined by their behaviour.
- Agents constitute a construct with states that varies over time.
- Agents are social, having dynamic interactions with other agents that impact on their behaviour.

Part of the process of developing the social simulation within our framework comprises determining the groups of individuals, their attributes, behaviour, interactions, and network memberships, which are all relevant for the social simulation scenario studied. Once these elements are defined, we incorporate them into the design of the agents that will mostly represent these societal stakeholders in the simulation environment.

7.2.2 Peacebuilding

Peacebuilding can be defined in a variety of ways, but there seems to be a consensus that peacebuilding is a multidimensional process of transformation from war to peace, aiming "to identify and support structures that tend to strengthen and solidify peace in order to avoid a relapse into conflict" (United Nations 1992, para. 21). The 'multidimensional process' encompasses a wide range of political, economic, developmental, humanitarian and human rights programmes, in order to address both the root causes and immediate consequences of a conflict. Since 1989, international peacebuilding missions have been deployed to a number of conflict-affected countries such as Angola, Mozambique, Rwanda, Cambodia and East Timor. Under the name of peacebuilding, the United Nations (UN) and other international organisations have undertaken programmes to prepare for, to oversee, or to administer elections in conflict-affected countries, to reform security sector, to strengthen the rule of law, to assist the process of disarmament, demobilisation and reintegration, to facilitate political dialogue and national reconciliation and to promote democratic governance.

Current peacebuilding research faces four major shortcomings. First, it adopts a top-down approach by focusing on formulating neoliberal policy "solutions" to fix the "problems" of conflict-affected countries (Richmond 2004). However, as it has been widely noted in relation to cases of peacebuilding in Iraq and Afghanistan (e.g. Berdal 2009), such solutions-oriented peacebuilding policy has not been effective because those states that received the neoliberal "solutions" are left with high levels of insurgency and instability after these peacebuilding efforts. We believe that peacebuilding "solutions" have faced problems because top-down policy solutions neglect perspectives of people in conflict-affected countries. The second shortcoming is Western-centrism. It is manifested in neoliberal policy 'solutions' which are formulated largely by the West (the US and Europe), to "fix the problems" of non-Western states, irrespective of local cultures and traditions. In addition, the role of non-Western emerging powers (such as those called BRICS - Brazil, Russia, India, China and South Africa - countries) in peacebuilding is understudied. These countries are increasingly more powerful and influential in conflict-affected countries, but the effect of their interventions cannot currently be predicted. The third shortcoming is a static nature of research. "Conflict" is often regarded as a bounded and one-time event, often predicated in descriptions of conflict with particular starting and end dates. However, "conflict is a social process in which the original structural tensions are themselves profoundly reshaped by the massive disruption of complex political emergencies" (Goodhand and Hulme 1999, p.18). It is therefore important to examine how people in conflict-affected countries interact and how such interactions affect peacebuilding efforts. The fourth shortcoming is that current peacebuilding research is fragmented. A small number of advanced studies take a bottom-up, local-culture-oriented, and/or dynamic approach to peacebuilding research (Hirono 2011), but none of them offers a robust quantitative framework that systematically analyses available data.

To address all the above problems and gain a more comprehensive understanding of the dynamics of perceptions and behaviours in conflict-affected countries, one needs to overcome the fundamental challenge that has contributed to the above problems - a lack of appropriate methodological tools. Our work attempts to overcome this methodological challenge by bringing computer science technology and social science studies into peacebuilding research. We offer a framework (from planning to implementation), with which peacebuilding researchers and other international relations entities can make qualitative and quantitative analysis simultaneously, and gain a comprehensive understanding of dynamics within the systems they observe. In short, we provide scholars and international policymakers a novel research framework, which will guide them step by step from creating stereotypes that represent the characteristics of the people (or groups of people) involved in conflicts and conflict resolution to implementing a multi-agent simulation model that can be used as an artificial lab to test the potential impact of different peacebuilding activities.

7.3 Framework

Our framework (depicted in Figure 1) captures two main activities: "toolkit design" and "application design". While in the toolkit design generic reusable components are created, in the application design we develop simulation models for specific purposes. A toolkit is designed once (and perhaps improved if required) and its components (agent templates and stereotypes) can be used for many applications (simulation models) that somehow relate to the general objective set for developing the toolkit.

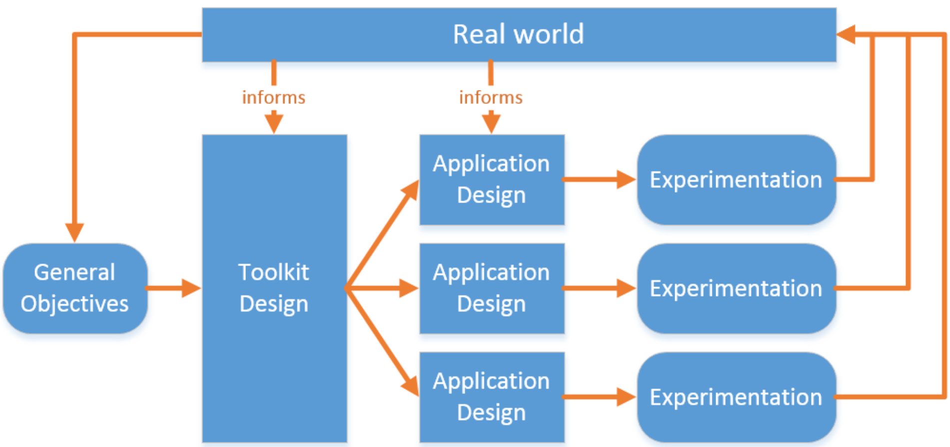


Figure 1: Overview of the framework

The purpose of our framework is to define a more formal approach to allow for the creation of generic templates to be reused and adapted within the modelling and development of social simulations. In addition, as contrast to employing existing, predefined social simulation tools, this framework seeks to empower researchers to design and implement their own entities. As a consequence, they have total control over the factors that might influence the dynamics of the system under investigation over time. It enables researchers to conduct artificial longitudinal studies of the social systems they are aiming to engineer. One can thereby test the short and long term impact of different interventions in the social system modelled.

The methodological basis for the framework is ABMS, which is particularly well suited to developing simulations of human-centric systems. ABMS became widespread in the early 1990s and is now well established in fields like economics, sociology, and political science (Squazzoni 2010). It is a bottom-up approach where real-world actors are represented as intelligent entities (agents) that have a memory, can make decisions, can interact with other entities and the environment, and can be proactive (Macal and North 2005). This simulation paradigm is chosen as it allows one to simulate the system from a position that values individual perceptions and behaviours (and their changes over time), and therefore it allows the study of the aggregate impact of all the individuals (i.e. the entire population) on social scenarios and, in particular, in situations in conflict affected countries. Our framework, however, goes beyond simply using ABMS and delivering models of peacebuilding activities in conflict-affected countries, which provides a one-off analysis of a particular region. Rather, it offers an innovative template-driven method for repeated model construction.

7.3.1 Toolkit Design

The toolkit design part of the framework consists of three main activities, once the objectives of the social simulation model are defined: (i) knowledge gathering; (ii) defining the stereotypes of relevant actors; (iii) using Software Engineering tools (UML/SysML) to create generic components in the form of agent templates that are capable of representing the different types of actors with regards to their attributes, behaviours and interactions in an abstract way. Figure 2 shows the general structure of this part of the framework:

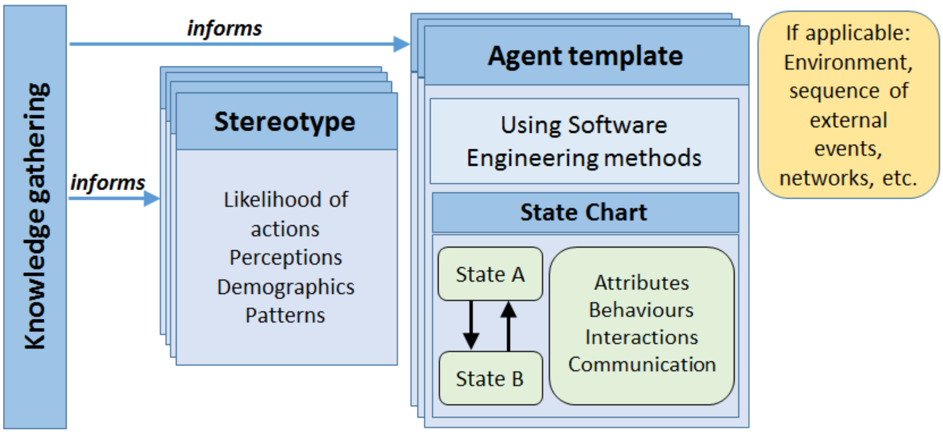


Figure 2: Toolkit design part of the framework.

In these three steps, knowledge about patterns, concepts, existing entities and the relationships among them are described, abstracted and finally represented in graphical notation (toolkit design). The description of external factors, such as the environment, events, networks, etc. can also be considered. Our focus in this chapter is to present how to produce templates that do not rely on specific simulation tools and provide a generic approach for reusability in social simulation engineering.

7.3.1.1 Knowledge Gathering

The initial step related to the toolkit design is to collect the knowledge regarding the model/scenario to be simulated. In social simulation exercises it has become a norm to build hypotheses and justify for the model construction by offering some empirical and theoretical facts. Diverse sets of data can be used based on the objectives established – from surveys and reports to theoretical models and observations in real-world settings (Moss and Edmonds 2005). In our framework, the knowledge gathered is employed (i) to describe the system studied; (ii) to inform the design of stereotypes and agent templates; (iii) to specify the agents and the simulation building; and (iv) to validate the results. Ultimately, we hope that the simulation results can also contribute to further knowledge about the system by providing insights into possible scenarios outcomes that might occur in the real world. In addition, this output might be useful to update or adapt the existing templates if necessary.

The process of extracting knowledge from the real world to build a toolkit can be done in different ways. Robinson et al. (2007) review and exemplify five approaches to empirically inform agent-based modelling: sample surveys, participant observation, field and laboratory experiments, companion modelling, and remotely sensed data. The authors describe each approach and discuss their suitability for the modelling process. According to Robinson et al., surveys, as part of the qualitative data pool, are useful to provide information on the distributions of characteristics, beliefs and preferences within a population of agents; to estimate behavioural models based on economic theory; to provide rough estimates of local-level change variables; and to identify constraints on decision-making. Field experiments address questions regarding resource use, whether or not it is possible to forecast subject behaviour, how changes in environment rules affect resource use and which competing theories best explain behaviour. Companion modelling helps designers to analyse the interactions among actors, their institutions, and the natural environment; to evaluate the process of collective decision-making as observed within the role playing game context; and to improve the stakeholder's knowledge of the diversity of perceptions and beliefs held in the community. Remotely sensed data answers question concerning the relative influence of biophysical factors that an agent will convert from one land use (i.e. human modification of the Earth's terrestrial surface) to another; how do biophysical factors interact to affect particular decisions; how do neighbourhood characteristics affect decision-making and how spatial relationships vary over time and space.

The type of method to be applied to the modelling depends very much on the problem domain, objectives, research questions, resources available, personal preferences and how familiar to the approach the modellers are. Furthermore, how the information gathered is incorporated into the model is determined by the level of detail required (Figueredo et al. 2014). For instance, most market dynamic models are based on theoretical assumptions and rely on empirical results to validate the theory (Parker et al. 2003). Other models, such as urban systems employ mass data and produce large scale simulations. Schenk (2014) propose model development based on stakeholders' descriptions and observation results in a political process scenario. Yang and Gilbert (2008) explore some of the methodological and practical problems involved in basing an agent-based model on qualitative participant observation (ethnographical data) and suggest ways of converting this information into rules that can be adopted by the simulation system model. Empirical material combined from different sources and mixed methods has also been adopted in modelling. A practical example is an agricultural land-use model, which was initially based on a number of theoretical assumptions combined with earlier empirical findings and further extended by results from qualitative interviews (Bhawani 2004). It is not our purpose in this chapter to perform an extensive review of methods of how knowledge gathering is performed for modelling. Instead, we just want to present some alternative routes that modellers can take when they reach this stage of our framework. For the large projects we work on, information comes from different sources and it is important to enhance the integration between different types of data, e.g. quantitative and qualitative, by performing information triangulation. In this manner the qualitative, quantitative and theoretical information can be checked against each other, thereby assisting to establish a more accurate picture of the system modelled. In our practical exercises employing the framework, therefore, in order to achieve the design objectives, we organise focus groups – internal ones (with the development team) and external ones (with the different stakeholders). The objective is to bring together a team of experts that provide theories, data (quantitative and qualitative) and knowledge regarding the real world system. The team is responsible for describing the system and also assisting in validating and translating this knowledge into the abstract templates in an interactive manner.

This process involves several meetings with the team, in which we clarified the toolkit design objectives, gathered ideas for relevant actors (a type of role played by an entity, e.g. peace keepers, citizens), stereotypes, use cases, and developed some initial state machine diagrams to define actors' behaviours. Once we gathered all relevant information, we worked on the main design, which is further discussed in the next sections. During this phase we conducted further internal focus groups to discuss improvements of the initial design and how to best translate the knowledge gathered into mechanisms or factors that we can model. We also considered the level of abstraction at this phase. As a final template design is achieved, we organised a final external focus group for its evaluation.

The last step of the knowledge gathering phase consists of defining the scope for the toolkit design. Here we look at the elements we want to include in the toolkit, considering agent types, environment, and psychological factors. We provide a table in which we list potential elements and factors, provide a decision of either including or excluding them, and provide a justification for this decision. This table is created during internal focus group discussions.

7.3.1.2 Stereotype Design

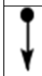
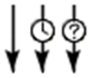
We employ the concept of stereotypes to establish patterns of behaviour, perceptions, habits, demographics, personality factors and emotional reactions which agents copy or emulate. A stereotype is a thought that can be adopted about specific types of individuals or certain ways of doing things (McGarty et al. 2002). The usage of stereotypes allows for a holistic approach, where the behaviour and characteristics defined are universally accepted within a domain area. The use of stereotypes in the design process, rather than solely extracting statistics from personal and/or demographics information, avoids discrepancies during the simulation validation process. Such disparities occur due to incorrect assumptions regarding groups of individuals in the population. For instance, if the designer specifies that in a model, single male individuals with age between 25-30 years, with a certain level of education behave or respond to the environment in a particular way (for instance, working class single males tend to adhere to violent acts as a response to high rates of unemployment in their country), this might not reflect the real-world scenario, as an individual's characteristics do not always have direct implication in their behaviour. Stereotypes, on the other hand, allow for a more flexible and accurate modelling of individual actions and responses.
The identification of stereotypes (i.e. the names of the different stereotypes) as well as defining categorisation criteria (i.e. the factors that identify stereotypical behaviour) is an iterative and sometimes also a laborious, long process. The modellers need to rely on focus groups, expert input and data analysis (data visualisation, feature selection, identification of clusters with patterns of behaviour, etc.) to determine what are the important patterns that emerge during the knowledge gathering that should be included in the design. For complex problems, involving multiple elements to be investigated/simulated, an agent can assume one or more stereotype. In addition, over the course of simulations, agents can change from one stereotype to another.

7.3.1.3 Agent Template Design

Agent templates define all relevant states, and all transitions between these states for a specific type of actor. These are organised in form of state charts and can be used as blueprints. An agent template can have multiple state charts, representing physical or mental states. The agent template acts as a pattern for creating virtual representations of typical real-world actors (e.g. drivers, citizens, peacekeepers).

To define our agent templates, we employ state charts from the standard UML. State charts are a graphical notation commonly used in Software Engineering for the purpose of software design. We advocate for the use of this tool as it describes the agents in an intelligible, intuitive manner, suitable for cross-disciplinary tasks, facilitating therefore the communication between the different stakeholders during the modelling process. The state charts represent the behaviour of an agent at discrete points in time. Agents assume an initial state in the start of the simulation and transit between states as the simulation proceeds. During the transitions between the states, actions may be executed. The main graphical elements of a state chart employed in template definitions are shown in Table 1.

Table 1: The main elements that constitute a state chart

Graphical element	Description
	State chart entry point: Indicates the initial state an agent is in once created.
	State: The particular condition that someone or something is in at a specific time. Composite state: A state that has sub-states (nested states).
	Initial state pointer: Points to the initial state within a composite state.
	Final state: Indicates the termination of a state chart.
	Transitions: These arrows indicate the movement between the states. They can be triggered by events (first arrow), timeouts (second arrow) or a conditional (third arrow).
	Branch: It represents the branching of transitions and/or connection points.

In our toolkit design part of the framework there is no link between stereotypes and agent templates and therefore both development processes are not directly related. However, the stereotypes should be developed before the agent templates to inform their design. Obviously, as this is an iterative process, amendments in both stereotypes and templates might occur until the final design is achieved. The stereotypes are going to be linked to the agent objects in the Application Design phase, as further explained in the next section. This happens after the Toolkit Design Phase is completed.

One question that might arise during creating an agent template is when a template should be considered finished, accurate, or ready, so that agents can be derived from it. There is no obvious answer for this question, as in Software Engineering templates can be re-used, modified and/or extended to adapt to new requirements. As a rule of thumb we consider that a template is ready to be employed to a simulation problem when it is able to capture (or represent) the behaviours of the stereotypes defined within the context of the domain model (or conceptual model). Defining a template is an iterative process, where several prototypes are produced and refined.

7.3.2 Application Design

The application design part of the framework consists of: (i) the development of a problem specific conceptual model and (ii) the development of the simulation model defining agent objects (which are instantiations of the agent templates) and their interactions (their communication and network of contacts) and behaviours (by linking them to a specific stereotype). The proportions within the stereotypes to be adopted in the simulation are informed by the real-world knowledge, conceptual model and the research questions regarding the scenarios simulated. Figure 3 provides an overview of the application design part of the framework

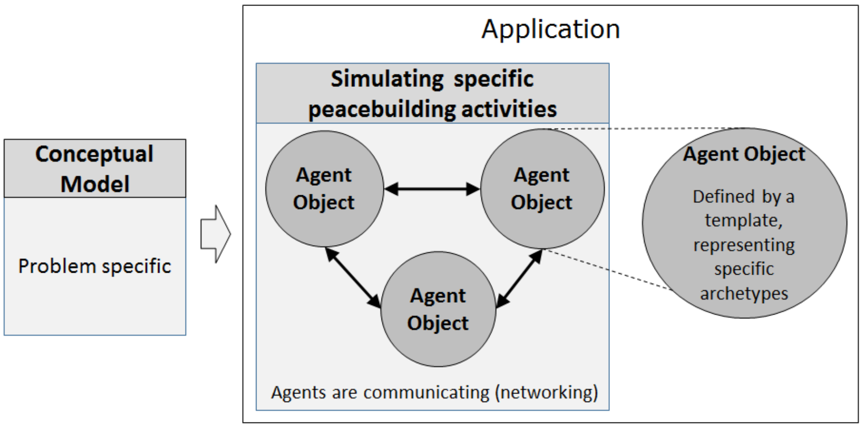


Figure 3: Application design part of the framework:

A simulation model should always be built for a specific purpose or set of objectives. For the application design we have to create a problem specific conceptual model which will lead to a problem specific application. Here we use the conceptual modelling framework from Robinson (2004) which consists of describing:

- Objectives:
  - The purpose of the model (e.g. the hypotheses to be tested)
- Inputs:
  - Elements of the model that can be altered
- Outputs:
  - Measures to report the results from the simulation runs
- Content:
  - Components represented in the model and their interconnections
- Assumptions:
  - Uncertainties and believes about the real world to be incorporated into the model
- Simplifications:
  - Reduction of the complexity of the model

For the content definition the model scope (what to include in the model) and level of detail (how to include it in the model) should be defined. For the implementation, the knowledge gathered also specifies the simulation parameters, population size, rates, etc. and assists in the simulation verification and output validation processes.

As the purpose of the toolkit design is to provide a complete, re-usable, extensible set of templates in a social simulation context, different application designs might employ distinct subsets of the available templates, depending on the problem to be simulated. The ultimate aim of using this framework for social simulation is to bring together a set of experts that will enable the creation of libraries (toolkits) of generic, re-usable templates of different social actors (individuals, organisations, government, peacekeepers, etc.) that can be combined together in a simulation design.

7.4 Illustrative Example of Applying the Framework

In order to demonstrate how the framework can be employed to create simulations that assist researchers in social systems engineering studies, we apply it to develop a toolkit for studying peacebuilding activities in general. Our application is developed for the specific case of studying international peacekeeping activities in South Sudan. Our objective is to employ the developed toolkit to design a decision-tool application that allows to investigate through "what-if" scenarios how Sudanese people respond to different governmental actions and societal interventions. In this tool, the user acts as "the government", taking decisions and applying several public policies to different regions of the country and observing the population's responses to these changes. The purpose of the tool is to allow policy makers and other interested parties to investigate peace keeping efforts in South Sudan and to evaluate how actions interfering in Security, Governance, Economy and Wellbeing might influence South Sudanese individuals towards violent acts, which are triggered by their levels of anger and fear.

7.4.1 Peacebuilding Toolkit Design

In this section we explain how the elements of the framework are employed to design the toolkit for peacebuilding simulations. We show how the knowledge was gathered and converted into stereotypes and agent templates. Subsequently we introduce how the toolkit was employed to develop the decision tool.

7.4.1.1 Peacebuilding Knowledge Gathering

Within peacebuilding context, the actors to be incorporated in the simulation model could be citizens and other peacekeeping stakeholders, as for example government officials, organisations, business people, industry, and the army. Moreover, we consider their actions (and perceptions) towards and in response to peacebuilding activities. To keep things simple, we decided to focus solely on citizens (using the South Sudan citizens as a representative example) and therefore the knowledge gathering activity sought to collect information regarding citizens' characteristics, habits and responses to conflict and peace keeping actions. In addition, we looked at individual behavioural changes, which are governed by their inner perceptions and emotions regarding their micro and macro environment. Consequently, we decided to adopt three foundational dimensions that influence individual behaviour: rational, emotional and social (Epstein 2014). The rational and social aspects are going to be modelled using knowledge obtained (i) from a report by the Centre for Nation Reconstruction and Capacity Development (CNRCD) on post conflict indicators in South Sudan (CNRCD 2011), (ii) from studies including Hirono (2011), and (iii) through expert input from political scientists. An expert in psychology provided the information regarding hypothetical individual actions and associated changes as a consequence of emotional reactions.

According to the findings of the CNRCD report, the four main indicators affecting violence in South Sudan are Security, Governance, Economy and Social Wellbeing. Each of these indicators is subsequently divided into several categories. For our tool design, during our focus group meetings, we chose those more relevant in our context, as shown in Table 2 below. In addition, information such as demographics per region, ratio between male and female citizens, and number of violent acts and regions with more propensity of violence was collected.

Table 2: Violence factors affecting South Sudanese people (derived from CDNR 2011)

Indicators affecting violence		
Factor	Category	Description
Security	Security forces	Effort to provide security to the population
	Attacks by rebel groups	
	Public perception of security	Individual fear of violence
Governance	Govern representation	Individual perception of being represented by the govern
	Fairness in justice	Individual perception of fairness in the justice system
	Citizen participation	Citizen participation in local govern
Economy	Inflation rate	
	Per capita consumption	
	Unemployment	
Wellbeing	Water sources	Access to improved water source
	Human rights index	A-E rating (for more see http://uhri.ohchr.org/en)
	Religious oppression	
	Tribal discord	Hostility between tribes increasing anger and violence

Individual perceptions, such as the feeling that the world is unfair, or perceiving uncertainty of the situation is shown to evoke emotional reactions, specifically anger and fear (Smith and Ellsworth, 1985; Kuppens et al., 2003). In return, emotional reaction bias people's future decisions: for example, individuals' experiencing fear tend to be more risk averse, while those who are angry tend to be risk-seeking (Lerner and Keltner, 2001). We incorporate to our knowledge pool, therefore, psychological mechanisms such as anger and fear, allowing individuals to change between neutral and emotionally loaded states of anger and fear. High levels of anger can trigger highly risky, impulsive behaviour; in our case it could be violence or participation in riots. High levels of fear increase risk-averse behaviours, i.e. migration, as individuals will want to move to safer areas with better opportunities. The values for individual anger and fear in our context are determined by the citizen overall satisfaction with the region they live in, how they perceive external events and their individual proneness to fear or anger. The satisfaction/perception of the external events is a result of govern/peacebuilding policies applied in that region.

This information was obtained during the course of four months, where we met with experts and discussed the population we wanted to model, their habits and the likelihood of their actions in conflict areas. The focus groups helped filtering the information to obtain what seemed to be more relevant to the toolkit design next steps. During this time, we also defined the scope of the toolkit, through several internal focus group discussions. In order to keep the model transparent, we decided to only model the citizens as agents. As stated before the whole development is an iterative process and we could always come back to this point to extend the scope of the toolkit. Table 3 shows the details related to the current scope of the toolkit.

Table 3: Scope to be considered for the toolkit design

Type	Subtype	Decision	Justification
Actors (these will be the agent objects in the simulation)			
Government		Exclude	Impact will be modelled through "Indicators affecting violence"
Oil Company		Exclude	Impact will be modelled through "Indicators affecting violence"
Citizens	Workers	Include	Key "role" to be considered in our model (employed/unemployed)
	Families	Exclude	Not considered to keep the model transparent (perhaps consider in future)
	Rebels	Exclude	To be defined as a "role" within the Worker actor
	Migrants	Exclude	To be defined as a "role" within the Worker actor
Peace keepers		Exclude	Impact will be modelled through "Indicators affecting violence"
Environment (here we consider the environment that influences the actors; usually in form of physical representations or resources)			
Weather		Exclude	Not directly relevant
Location		Include	For being able to provide graphical representations of segregation
Networks		Exclude	Not considered to keep the model transparent (perhaps consider in future)
Peace keepers		Exclude	Impact will be modelled through "Indicators affecting violence"
UNO		Exclude	Impact will be modelled through "Indicators affecting violence"
Local police		Exclude	Impact will be modelled through "Indicators affecting violence"
Businesses		Exclude	Not considered to keep the model transparent (perhaps consider in future)
Job Vacancies		Include	Will be a resource (number of vacancies)
Money		Exclude	Not considered to keep the model transparent (perhaps consider in future)
Weapon delivery		Exclude	Not considered to keep the model transparent (perhaps consider in future)
Interventions by	Homeland	Exclude	Can be set by "Indicators affecting violence" (experimental factors)
	UNO	Exclude	Can be set by "Indicators affecting violence" (experimental factors)
Indicators affecting violence		Include	Experimental factors (economy; security; governance; wellbeing)
Psychological factors			
Anger		Include	Anger/Fear model considered in form of state variables
Fear		Include	Anger/Fear model considered in form of state variables
Hate		Exclude	Expressed by consideration of Anger/Fear
Trust		Exclude	Exclude due to time constraints; to be added in future
Fairness		Exclude	Exclude due to time constraints; to be added in future
Violence		Exclude	Defined by the "indicators affecting violence"
Representativeness		Exclude	Represented by "indicators affecting violence"

7.4.1.2 Peacebuilding Stereotype Design

In our example, we have citizens that respond to peace keeping efforts based on what they perceive as satisfactory in terms of Security, Governance, Economy and Wellbeing. If individuals do not feel well represented according to these four factors, which will determine their levels of anger and fear, they will respond either with violence (when there is high anger) and/or migration (when there is high fear). In addition, peacekeeping activities aim at reducing violence and the number of refugees in conflict areas. Having this information and the objectives in mind, we defined three citizen stereotypes. The first stereotype is the "Fighter". This is someone with high anger and low fear, having a high likelihood to participate in outbursts of violence in response to changes in their environment. The second stereotype is the "Conformer". This is someone with moderate anger and fear, who tends to be less likely to migrate or participate in violent acts. The third stereotype is the "Refugees". This is someone with high fear and low anger, who has a high likelihood of migrating to areas of less conflict. Table 4 shows a summary of the definition of these stereotypes.

Table 4: Citizen Stereotypes

Stereotype	Likelihood of violence	Likelihood of migration	Anger level	Fear level
Fighter	High	Low	High	Low
Conformer	Moderate	Moderate	Moderate	Moderate
Refugee	Low	High	Low	Medium

This is only one possible group of stereotypes suitable for this problem which we employ in this example for simplicity of presentation. Other stereotypes can be defined if there is the need. In addition, when different populations are considered in the simulation, for instance, government, peace keepers, industries, etc., these should also be included in the stereotype set, with their own set of patterns of behaviours.

7.4.1.3 Peacebuilding Agent Template Design

When developing agent templates, it is good to start with a very simple prototype and then work towards the final template by adding more details. One thing that is quite difficult, in particular for modelling novices, is to find the right level of abstraction (a model is always a restricted copy of the real world, and is created through abstraction). There are no strict rules for this process and it needs some experience to work it out. A good approach is to follow the KISS principle (keep it simple, stupid), which was introduced to ABMS by Axelrod (1997). It states that only essential elements and relationships should be considered within the model. It does not state how to know what is essential. A good way to gain experience in this process is to look at model examples, which are usually shipped with the software tools.

Our population is composed by junior, adult and senior citizens. With time, junior citizens become adults, adults become seniors and seniors die (for simplification, let us not consider that there is the possibility of junior or adults dying). Therefore our actor (citizen) can be represented by a state chart with junior, adult and senior states (Figure 4). The transitions between these states occur as the individuals reach age thresholds, i.e., 18 to transit from junior to adult and 65 from adult to senior. As these transitions are triggered by the individual age, which increases with time. The state Death is also included to finalize the life cycle of the agent.

To start building a general template for representing citizens in conflict areas, it is necessary to know who the actors in our model are. Our actors, as mentioned previously, are the citizens. We decided to start with modelling citizens' life stages: junior, adult and senior citizens. These are the first three states we add to the state chart that will become the basis for our template. The transitions between these states occur as the individuals reach age thresholds, i.e., 18 to transit from junior to adult and 65 from adult to senior. As these transitions are triggered conditioned by the individual age, the attribute age and an event to increase the age with time are defined. The state “death” is also included to finalise the life cycle of the agent. Figure 4 shows the early prototype state chart. This prototype could be implemented and we could create an application with an aging population. Having an application at this stage allows us to test the basis of our future template.

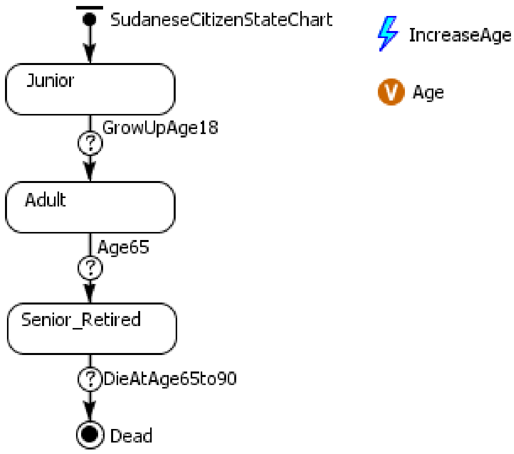


Figure 4: Citizen in conflict areas (early prototype)

As we have shown in Figure 1, the process of stereotyping and creating the templates is informed by data, theories, expertise knowledge, etc. Apart from the theory employed, in order to complete our template, we had the assistance of one of our team members, who is a political scientist, who provided us with further information, as described below and in (Hirono 2011). Therefore, we had further guidance regarding the states and attributes found necessary in our diagram, in a peacebuilding context.

The states are defined as follows. Citizens could be in "unemployed" state. In this state they can either be in a (nested) state "looking for a job" or in a state "loafing around". If a long time elapses while in the state unemployed, dissatisfaction and therefore anger raises, which might trigger violent behaviour. If individuals become part of a rebel movement, they can move to the state "arrested", the state "recruit" (where they enrol other individuals to help with acts of violence) or the state "dead". Conversely, if they are successful in getting a job, they assume the "employed" state. While employed, they can be in the states "at home" or "at work". This location differentiation can be useful when/if individual emotions modify or are influenced by the environment or the person's network of contacts, for more complex simulation models. When citizens are located in violent areas, their fear increases and they migrate.

Furthermore, we added some more avenues towards death. If citizens have premature death, the dead state assists us to identify what triggered the transition that led to this state (e.g., cases of violent acts). As noted in the system description, employment appears to be an important factor for adults, as they are more likely to get involved in violent activities when there are no jobs available.

We also add four attributes to the template: the parameter Male to indicate whether the individual is male or female; the individual thresholds of anger and fear that would prompt a transition to be violet or migrate, respectively. This provides diversity to the population, as each citizen will have a different threshold; and the attribute ProneToRebel, which determine whether a violent individual is likely to join rebel groups based on the anger level. All these parameters allow for variability and flexibility of the model. In addition, the parameters and rates at which transitions and events occur are to be determined by data and/or information about the population. Figure 5 shows the final template for citizens in conflict areas.

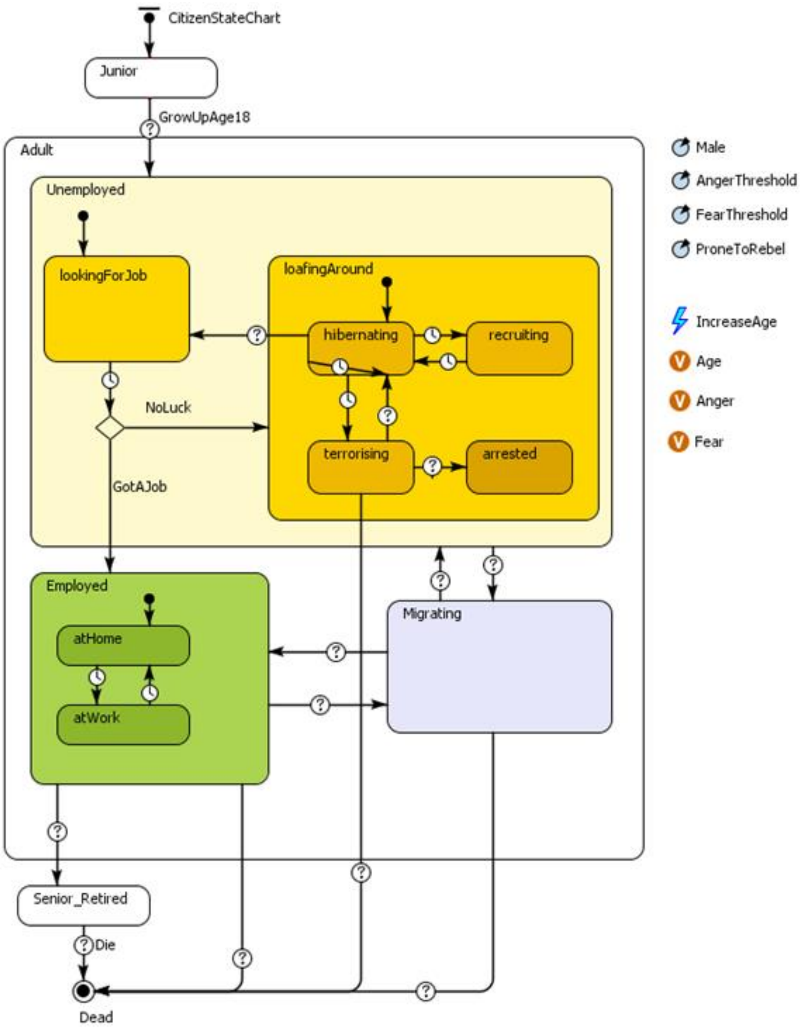


Figure 5: Citizen in conflict areas (final template)

The template is ready to be employed in other peacebuilding modelling and simulation activities. It is generic enough so that other researchers can re-use it in their peacebuilding simulation studies. It is our intention in the future to extend our framework and create a library of templates with other actors involved in peace keeping activities (organisations, foreign peace keepers, govern, business people, army, etc.).

Additionally, the framework can be extended by other users. Therefore, if one feels that the template provided is not suitable for their particular problem, further knowledge can be employed to modify the existing templates. In the case of the template of Figure 5, for instance, one could re-use the outer shell of the template, i.e. the states Junior, Adult and Senior_Retired and modify the states inside to better suit the problem addressed.

7.4.2 Peacebuilding Application Design

Now we use the newly developed toolkit to develop a specific application: a decision-support tool for studying the impact of different peacebuilding activities for the case of South Sudan. The tool was developed mainly for the purpose of testing the usability of the toolkit. But it is also part of a proof-of-concept study, where we were aiming to better understand the principle dynamics and opportunities of social systems engineering within the context of South Sudan. We have used the decision support tool during our multidisciplinary focus group discussions while we were writing a larger funding proposal, related to peacekeeping activities in South Sudan. For the development of this specific application we used knowledge about the situation in South Sudan, on the one hand gained from the literature, and, on the other hand gained from the expertise of the multidisciplinary focus group members.

The initial step in the application design is the development of a conceptual model. Here we should look back at the objectives and scope definitions of the toolkit design (if available), and adapt these to fit the purpose of the application design (which is usually a special case of the more general one for the toolkit design). In our case, rather than focusing on peacebuilding activities in general (toolkit objective) we focus on peacebuilding activities in a specific location - South Sudan (application objective). For the conceptual modelling we follow broadly the ideas of Robinson (2004), defining objectives, inputs, outputs, content, assumptions, and simplifications.

- Objectives:
    - To better understand the impact of different peacebuilding activities (defined through indicators affecting violence) for the case of South Sudan

- Inputs (things we can vary during runtime):
    - Security: Security forces
    - Governance: Govern representation; fairness in justice; citizen participation
    - Economy: Inflation rate
    - Wellbeing: Water source; human rights index; religious oppression; tribal discord

- Outputs (responses from the model that help us with achieving the objectives):
    - States of the adult population (unemployed; employed; migrating) [% of population]
    - Population anger level [% of population]

- Content:
    - Scope is identical with that defined for the toolkit (see Table 3); the only difference is that we are focussing on a specific conflict region: South Sudan

- Assumptions:
    - Changes happen 24/7 (we do not consider time of day / day of week).
    - Initial values and relationship dynamics are based on best guesses

- Simplifications:
    - These are listed in the scope definition of the toolkit (see Table 3)

For the application implementation we use AnyLogic University v7.0 (The AnyLogic Company 2016), a multi-method simulation IDE that allows the automated translation of state charts into java code. Our decision support tool consists of a Graphical User Interface (GUI) to make it easy to use and informative. Underneath the hood of this GUI we have created an agent population representing South Sudanese citizens, by linking each agent to a specific stereotype.

The variables shown in Figure 6 are those employed to run simulations to study the dynamics of anger and fear, and therefore the occurrences of violence and migration. In the environment, everything besides the South Sudanese people (i.e. peace keeping factors of Table 2) is modelled using variables that can be changed (by researchers) before and during the simulation. The diagram of Figure 6 shows all the variables that affect individual emotions in the tool. The levels of anger and fear depend on the outcome of the weighted sum of all these variables. In the diagram, the circles with a “V” inside represent the variable numbers that will emerge (and change) as the simulation is run. For instance, the number of rebels will increase if the policies from the government generate anger. The dark circles are the main factors of the sum. Each of these factors is a combination of other variables. For instance, the Economy factor is a combination of the inflation rate (which is a parameter modifiable by the user), the per capita consumption (which is calculated based on the inflation rate of the country) and the number of job vacancies (which is variable). It is up to the user of the decision tool to define these values and the weights of the sum based on real-world information about Sudan and analyse how changing the policies (sliders in Figure 7) affect the behaviour of the agents (citizens). As we do not have information regarding job creations, we defined it as a constant rate in the system (in the top rectangle of Figure 6 the cloud named JobCreation represents a constant input of new job vacancies).

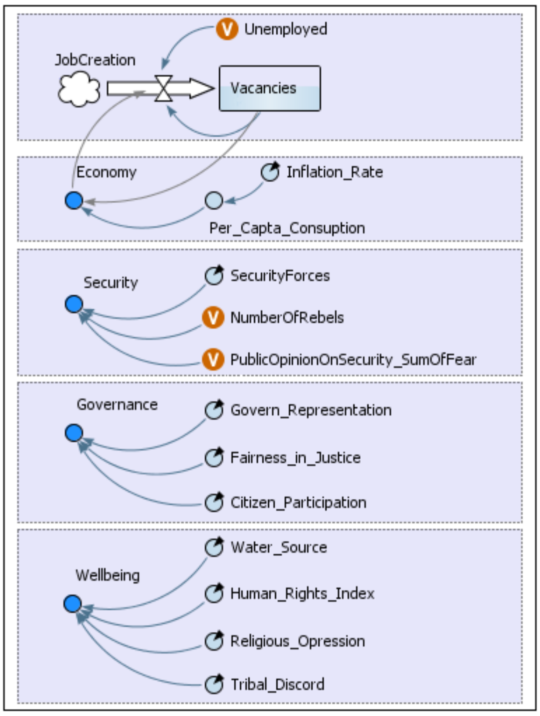


Figure 6: Variables included in the decision to study the dynamics of South Sudanese citizens

The GUI is designed to allow easy access to the parameters which can be changed even during runtime. Figure 7 shows a screenshot of the main screen of the tool. The user can modify the values of the Security, Governance, Economy and Wellbeing variables (even during runtime) and observe how the behaviours and numbers change over time for several scenarios.

Figure 7: Screenshot of the decision tool main screen.

The left panel shows the state of the individuals (at home, at work, looking for job and rebellious) and the amount of citizens (agents) in each state. In the right side of the screen the user has the possibility of changing the peace keeping variables by using the sliders and observing the impacts of these changes. For example, if the citizen participation is reduced, it will generate more anger and as a consequence more citizens become rebellious and therefore the number of agents in the box Rebellious will increase.

The charts tab provides access to population statistics. Figure 8 shows an example of statistics that can be collected as output. The x-axis is the number of periods of the simulation, which can be days, months, etc. The y-axis represents number of agents in each category. The user of the decision tool can observe when the outbursts of anger and therefore violence occur and the reasons associated (e.g. the growth in unemployment). The user can also observe the numbers of migrants and how they arise due to increased violence.

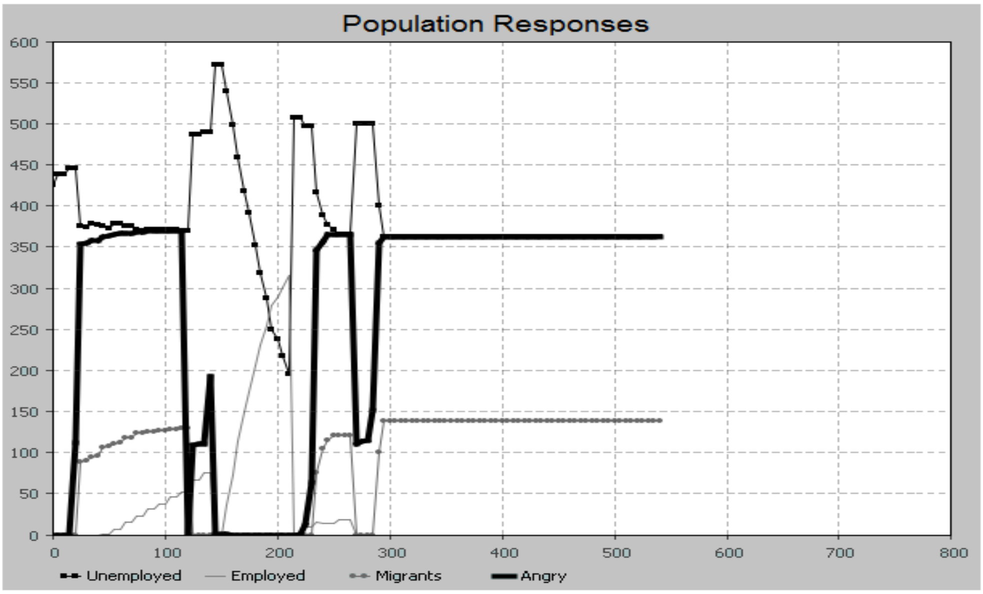


Figure 8: Sample output

7.4.3 Engineering Actions and Interventions in a Peacebuilding Context

As this tool is an illustrative example only, further data is necessary to validate the outcomes produced. However, once the parameters of the tool are adjusted to assume those values close to the current context of a country (in our case, South Sudan), several scenarios can be validated, studied and evaluated by peace keeping policy makers. Experimental results are therefore useful to better understand social phenomena or, in our case, the impact of peace building activities on the psychological and physical state of the individual citizens (micro level). For instance, an investigation on which factors are primarily responsible for migration or outbursts of violence and how these numbers alter as a result of changes in the current policies. Furthermore, the scenario outcomes also indicate the impacts of global measures (macro level) as for example employment rate; financial measures; level of unrest in the country, etc.

Such decision tool can also be employed as an educational or communication interactive instrument by demonstrating politicians and citizens the consequences of behaviours such as radicalisation. For example, in some public engagement settings such a science fair or exhibition at a museum, public members could change the sliders themselves to see the micro and macro impacts of different options and compare alternatives. Through this exercise public will learn implications of various actions on the population in general as well as individual groups of citizen. For instance, the figure below (Figure 9) shows the results of experiments where measures are taken to secure safety and employability of the population. As the number of unemployed people decreases, together with their perceptions of security and representativeness adjusted in the sliders of the tool, shown in Figure 7), the number of migration and outbursts of violence (represented by the number of angry citizens) decreases.

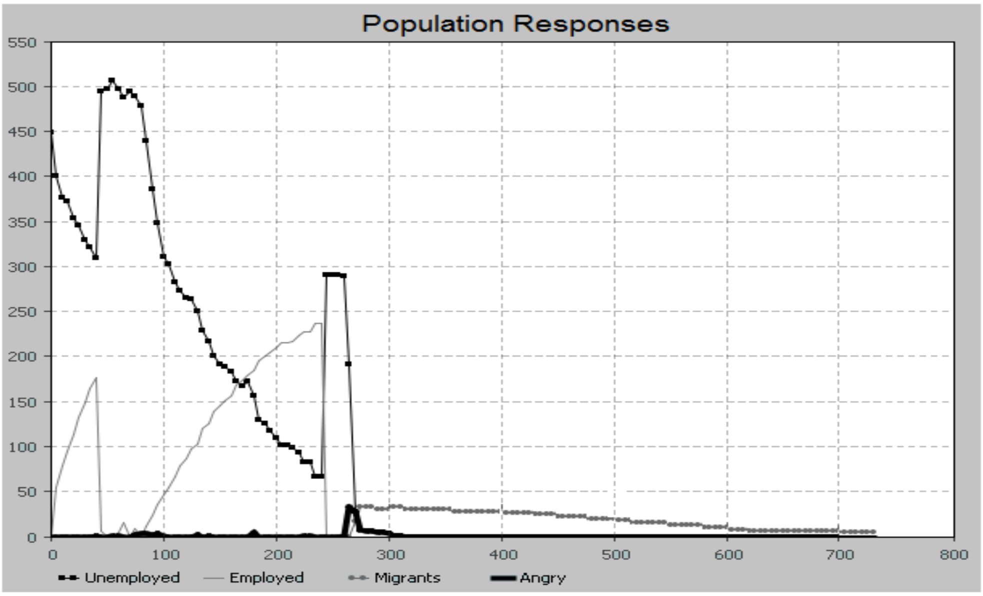


Figure 9: Example of the use of the tool to test actions towards creating jobs and increasing safety and representativeness.

7.5 Conclusions

In this chapter we presented a novel framework that employs Software Engineering methods to build agent-based social simulation models. The objective for developing this framework was to enable researchers to conduct artificial longitudinal social systems engineering studies in which they have control over factors influencing the development of the system under investigation over time. Therefore, one can test the short and long term implications of different interventions on the evolution of social systems. We have illustrated the application of this novel framework through the development of a decision-support tool for studying the impact of different peacebuilding activities in South Sudan. We believe that the framework will be easy to use by a multidisciplinary team for the development of models supporting social systems engineering studies, as it employs clearly defined steps and a simple graphical notation for the conceptual modelling which can then be implemented using simulation software packages that support automatic translation of state charts, as for example Repast Simphony (Argonne National Laboratory 2016) or AnyLogic.

A possible next step in this project would be to turn the illustrative example into a case study. This would require some additional data collection with focus on South Sudan and a better understanding of the dynamics of anger and fear, and therefore the occurrences of violence and migration. The latter we could get from the literature and by talking to domain experts. It would also be interesting to apply the framework we presented here to multidisciplinary projects in other domains. A potential application area would be "Sustainability and Resilience of Cities" which is one of our current research priority areas. We could use this framework to build models that allow testing the impact of social systems engineering on the sustainability of urban habitats.

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