MIGRATION AMONG SIMULATION PARADIGMS AND TOOLS

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ABSTRACT

The Simulation is used as an active research method when analytical solutions are inconvenient or even impossible. One problem is the incompatibility of created simulations on a tool level, but other - is model incompatibility because of different simulation methods. The article dealt with determination of basic principles for effective model migration and accentuates the use of appropriate simulation methods for the development of specific model groups.

Keywords: simulation, migration, system dynamics, agent-based models

1. INTRODUCTION

A typical research object of simulation is sociotechnical systems with a significant number of important parameters that are usually stochastic. Several simulation technologies exist corresponding to the nature and conceptual model of the target system, for example discrete-event systems (DEVS), system dynamics (SD), agent-based simulation (ABM) (Bruzzone, Verbraeck, Ginters et.al. 2002; Ginters et.al. 2011) and others. However some problems remain. First, is the incompatibility of created simulations on a tool level. This is usually addressed by defining common data exchange rules, creating joint communication environments (CORBA, ECE, HLA) (Aizstrauts et.al. 2012; Zhang and Deng 2012) or even shells for data query processing (SimQL/SimAL, MeshSQL) (Wiederhold 2002). The second challenge is model incompatibility because of different simulation methods. As any software can be written in almost any programming language, any simulation model can be developed using any of the before-mentioned simulation methods. However, developer work efficiency and the computing resources required to run the model will differ. Quite often models developed using one simulation method have to be altered to use another to ensure integrity in a unified environment, as well as to avoid using specific communication tools.

The most common model migration type is from SD to ABM and vice versa (Wakeland et. al. 2004; Norling; Scholl 2001; 2007; Macal 2010; Figueredo and Aickelin 2011; Ahmed, Greensmith and Aickelin 2012; Ahmadizadeh, Teose and Gomes 2011).

SD (sometimes called differential equation modeling or dynamical systems modeling) concerns itself with the high-level behavior of a system or macroscopic view. It helps to understand the aggregate operations of system on a macro-scale. It is great for cutting away unnecessary detail and focusing on what is truly important in a model. SD models are constructed from set basic building blocks also known as "primitives". The key primitives are Stocks, Flows, Variables and Links (Insight Maker 2014).

ABM allows to model individual agents within a system. Where in SD might only look at the system as a whole, in ABM is possible to model each individual element and explore the differences and interactions between these elements (NetLogo User Manual 2013).

It would be reasonable to determine of basic principles for model migration and accentuates the use of appropriate simulation methods for the development of specific model groups. Further analysis will be performed based on a practical example: Insight Maker (Insight Maker 2014) SD model migration to an ABM simulation model, as well as to an ABM model in the NetLogo (NetLogo User Manual 2013) environment.

Several comparative studies between ABM and SD have been undertaken (Jaffry and Treur 2008). Some notable discussions in these studies include the issue of computing power and control. In some studies, it also the case that the ABM is computationally expensive compared to the classical mathematical model although this may be overcome in future by highly parallel computing architectures (Tang et al. 2008). Traditional continuous models are generally easier to implement but many aspects of biological systems are intrinsically stochastic in nature (Wilkinson 2009) so the ABM could be viewed as a more „faithful interpretation of the processes being modeled (Ahmed et al. 2012).

Ahmed et al. (2012) in their studies shows that ABM is able to capture natural variation without recourse to modification of any parameters for a simulation. The classic SD model has no variation. Therefore an ABM with tool that has built-in randomness is able to capture the natural variation better than a classic SD model simulation. The source of variation for the ABM is the contact between the agents between the different experiments. (Ahmed et al. 2012)

As Figueredo et al. (2011) shows in the results of their experiments that there are simulation cases where SD and ABM derived from the same mathematical model do not have the same output. Therefore, it is not possible to compare which approach would be more suitable for some situations. Similar conclusions draw Macal (2010) in his research for example the equivalency of the model results is not exact in terms of numerical accuracy for the reasons noted. The ABM is able to provide additional information over what the SD model provides due to the explicit stochastic nature of the ABM.

2. DEMOGRAPHY MODEL IMPLEMENTATION UNDER DIFFERENT PLATFORMS

2.1. System Dynamics (SD) Simulation under Insight Maker Framework

SD modeling essence is based on the data set that have common characteristics, and which can form common types of activities. For this type of models the main concentration is to the stock. There are not separated individuals and different type of activities can be performed for the stock as a whole.

Initial conditions were to make SD demography model to demonstrate demographic changes in a small country like Latvia. The model has to be made under Insight Maker framework. The results of the model have to show demographic changes in the country in the time period of 20 years.

In Figure 1 there is illustrated a simple representation of a Population using SD Stocks and Flows made using Insight Maker tool. There is the single Stock in the middle of the model, “population”, which represents everyone who is alive in this population. There is only one Flow going into population, called births and one Flow out, called deaths. There are also four variables that is neither a Stock nor a Flow. Flow called “birth” that represents “birth per year” is dependent from “birth rate” and “population”. But “birth rate” is dependent from “possibility of birth” that just adds simple random possibility.

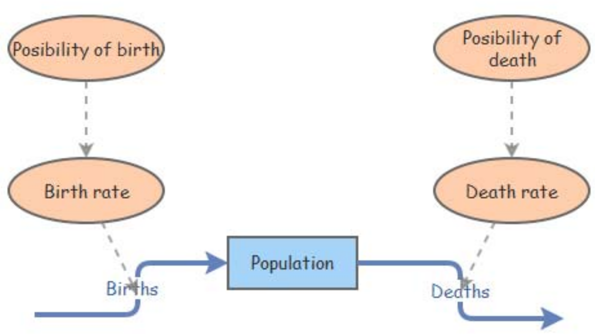

Figure 1: SD model displaying the demographic changes with Insight Maker

Plot graphs in the Figure 2 shows the SD model for simulating demographic changes. Model is very simple and there is only birth rate and death rate that is taken into account just to show a modeling with Insight Maker. Plot graphs shows population decreasing in this specified situation.

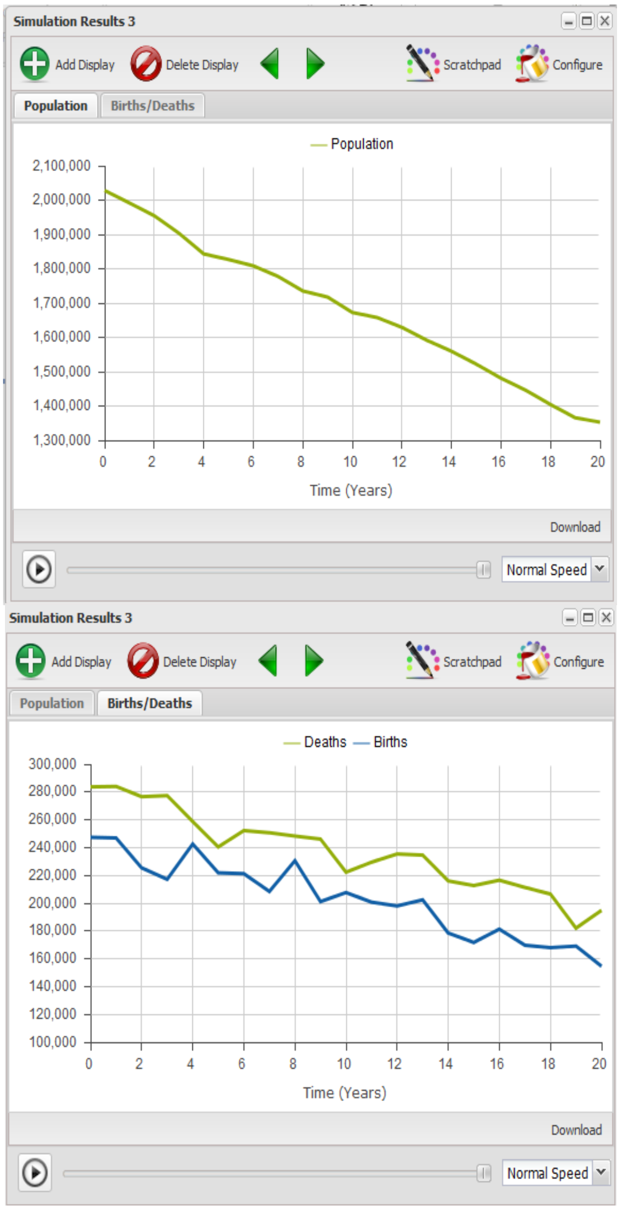

Figure 2: Results of population SD model made with Insight Maker

As it is shown in the Figure 2 in the upper image that with the conditions that have been put in the model, that demography in the time period of 20 years in these conditions is decreasing. The reason for population decreasing is that death level in the population is higher than birth level in the population as it is seen in the lower image of the Figure 2.

The SD approach deals with a population as total rather than with individual humans. The simulation calculates the total population of human at each time step, but each individual is not represented. This makes it hard to model relationship among the humans. This type of simulation is good for simulating a population in some region or to compare it with another region. SD should be used to simulate a population of human as a whole.

2.2. Insight Maker Use for Agent-Based Modeling (ABM)

The ABM main concentration is on each agent separately. Each agent has certain characteristics and with that various types of operations can be performed. In ABM there can be distinguished different types of agents as well.

For modeling demographic situation in ABM style there is the agent - human that has its two main stages – alive or dead. But in SD there is main stock that consists of several agents that has similar stages – alive or dead. In each of these modeling styles these stages could appear different depending on simulation tool specifics.

In this case, the SD model has been modeled the demographic situation for a specific place so in this particular case agent will be a human. Due to the fact that there has been modeled human birth rate and death rate in the system dynamics model, which means that in some way, either as a state or as characteristics of the agent there has to appear the birth and death rates in the agent-based model. Depending on various simulations modeling applications execution of some things can be different but the result stays the same.

Initial conditions for ABM using Insight Maker environment were similar to SD model – to make demography model to demonstrate demographic changes in a small people environment. The results of the model have to show demographic changes in 200 people environment in the time period of 20 years.

Unlike the SD population model where model is based on stocks and flows, the population ABM works with conditions and actions. In order to simulate a population there has to a separate agent for each individual in that population. Each of these agents has a set of attributes that defined their state. States represent the condition someone is in. In this sample use case there is only one state for “human” and that is “alive” as it is shown in Figure 3. There are two actions – “births” and “deaths”. An Action can be used to manipulate a model during a simulation, in this case, to get human to be born or to be dead. When agents in this model die, then they have been deleted from model therefore there is no need for state “dead” for agents.

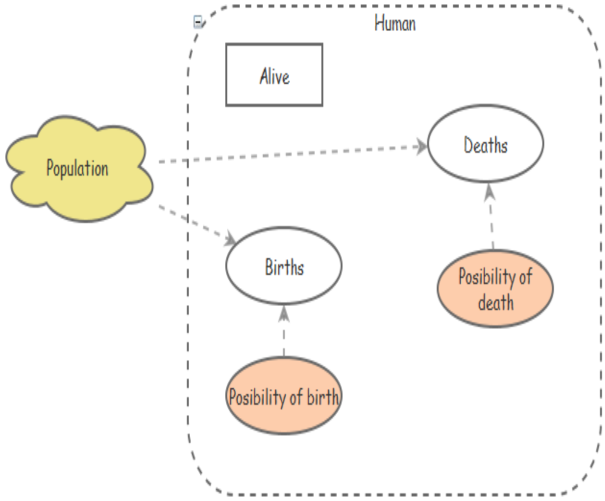

Figure 3: ABM that displays the demographic changes made with Insight Maker

Plot graphs in Figure 4 shows agent based population model with Insight Maker in time of 20 years. Plot graphs for agent based model approach are very similar to SD models.

Since in the demography ABM initial amount of population was 200 people, then the results is hard to compare with previous but as it is seen in Figure 4 that also in this case population curve is decreasing, so comparing these results it can be concluded that results coincide. Exactly like previous model also in this the reason for population decreasing is that death level is higher than birth level.

Insight Maker has lot of convenient menus and graphical model construction, so it is easier to make a System Dynamics model, but for making an Agent Based model these pop-ups and buttons makes it more time-consuming to make an agent based model because it’s not as intuitive as it should be for this kind of simulation tool.

Also ABM is not very suitable for modeling conditions where there is a lot of agents with similar conditions especially Insight Maker as an environment is not made for modeling large amount of agents.

It is hard if not impossible to model a simple population model within a region like Latvia not to mention for larger countries using Insight Maker environment.

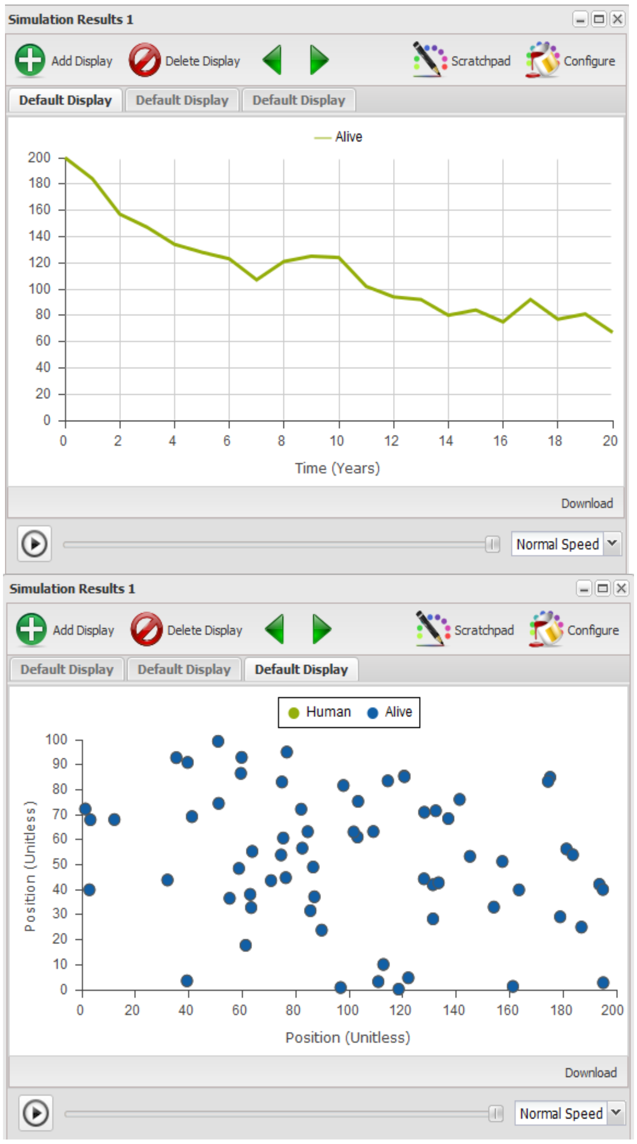

Figure 4: Results of population ABM made with Insight Maker

And also ABM should be used to model tasks where individual approach for modeling agents is needed. Modeling large amount of same type of agents like in population model is not even hard to do in Insight Maker environment but also it is not very practically used recourses.

2.3. Multi-Agent Simulation in NetLogo

The ABM will allow the exploration of a range of variations that would be difficult (if not impossible) to encode in the SD model. The SD model has provided some results that are of interest to some fields for example to ecologists; ABM provides a tool for further exploration of the results carried out in SD model, and possibly an understanding at the micro level of why they are so. Furthermore, the ABM provides the opportunity to examine the impact of the assumptions that are encoded in the SD model (Norling 2007).

Initial conditions for ABM using NetLogo were to make demography model to demonstrate demographic changes in a small region. Conditions for NetLogo eenvironment were a little bit more complicated – there were separated women population and men population separately.

Unlike the agent based model in Insight Maker in order to make an agent based model in NetLogo user has to write almost everything using programming language as it is seen in the Figure 5.

```
breed [women woman ]
breed [men man ]

women-own [ age ]
men-own [ age ]

globals [random-birth]

to birth-women
   set-default-shape women "person"
  create-women initial_number_of_women [
    set color red
    setxy random-xcor random-ycor
    set age random 70
    ]
end

to birth-men
  set-default-shape men "person"
  create-men initial_number_of_men [
    set color blue
    setxy random-xcor random-ycor
    set age random 70
    ]
end

to Setup
  clear-all
  reset-ticks
  birth-women
  birth-men
end

to Go
  tick
  if not any? turtles [ stop ]
  ask turtles [
    right random 50
    left random 50
    forward 1
  ]
  ask men [
    if age > max-age_of_men
    [ die ]
    get-birth
    set age ( age + 1 )
  ]
  ask women [
    if age > max-age_of_men
    [ die ]
    get-birth
    set age ( age + 1 )
  ]
end

to get-birth

  set random-birth ( random 2 )
  if random-birth = 0 [
    birth-male
  ]
  if random-birth = 1 [
    birth-female
  ]
end

to birth-male
  if random-float 200 < men_birth_rate[
    hatch-men 1 [
      rt random-float 360
      fd 1
      set age 0]
  ]
end

to birth-female
  if random-float 200 < women_birth_rate[
    hatch-women 1 [
      rt random-float 360
      fd 1
      set age 0]
  ]
end
```

Figure 5: Source code for ABM displaying the demographic changes made with NetLogo

It makes it difficult for modeling opportunities for end-users in NetLogo environment but for more advanced professionals it creates the conditions which can lead to much more complex models. In order to make agent do anything, there has to be written a procedure. Similar to any other programming language with these written procedures there are a lot of possibilities that can be made in this simulation tool.

In Figure 6 it is shown that in this population simulation model button "setup" calls procedures that create women and men. Button "Go" allows agents to move around and interact with each other. When each and individual agent age has reached maximum then agent dies. Population births and deaths are also affected by birth rate.

In this ABM it is possible for user to interact with model more easier because there has been made slots for initial number of men and women, maximum age of men and women and women's and men's birth rate.

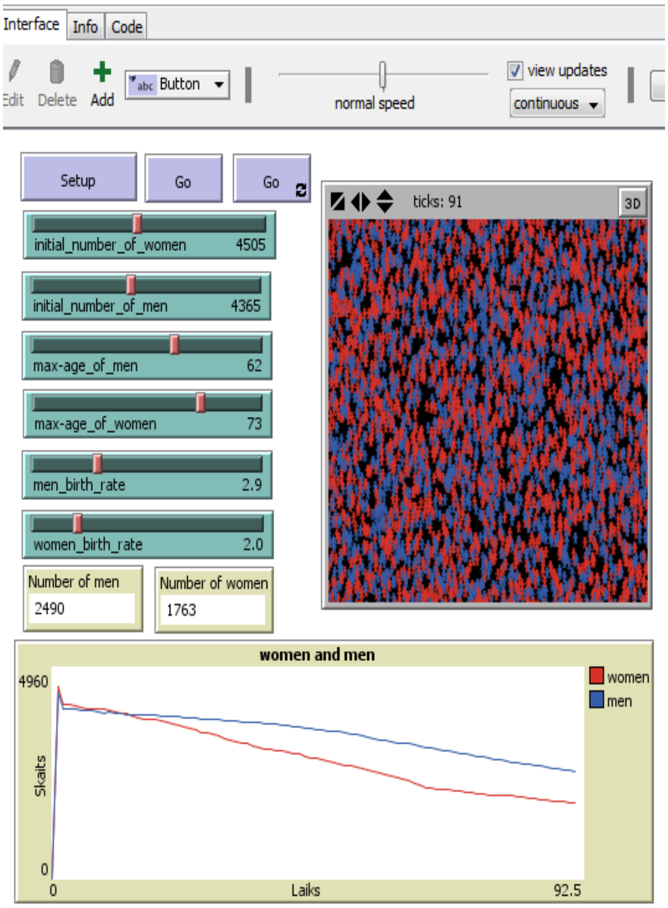

Figure 6: An interface window of the ABM that displays the demographic changes made with NetLogo

The results of the ABM in NetLogo also shows that population with these types of conditions is decreasing. Despite the fact that there has been added some extra functions in the model that wasn't in previous models, simulation results stay the same.

NetLogo as a tool is more convenient to simulate the conditions with large amount of agent because it has more recourse that processes all these agents. But despite that ABM should still be used for more individual tasks that can't be done by SD modeling. Also comparing NetLogo with Insight Maker for modeling in NetLogo environment user needs to be having more programmer skills to make more complicated models. In order to make some model in NetLogo environment user needs to write it programming code.

3. STEP BY STEP FROM SD TO ABM - IS IT REASONABLE?

In order to move from SD modeling to ABM there has to be certain steps that need to be followed:

- Step 1 – in the SD model's stock find out what is the agent. Define what the agent is;
- Step 2 – when the agent is founded the next step is to define what kind of characteristics or stages the agent has to have;
- Step 3 – after finding out what the agent is and what kind of characteristics or stages the agent has the next step is to find out what types of activities will be conducted with these agents in order to get the needed results.

Building SD tasks in ABM environment is quite inexpedient because a lot of resources are consumed in the model to simulate each individual agent separately. Tasks that are modeled in the SD environment usually requires large amount of different types of agents with similar types of activities. Migration from SD to ABM for these kind of tasks that requires large amount of agents with similar states of activities are very unreasonable due to the fact that these large amount of agents with similar states doesn't affect each other. Simulation tools needs to simulate each of these agents separately meaning that it takes a lot of resources to simulate that kind of model and if these agents doesn't affect each other at all then migrating it to ABM loses its point.

Tasks that require agents to interact with each other are more useful to migrate from SD to ABM because of the fact that modeling situations where agents interact with each other are more precise in ABM than SD. That means when these kinds of tasks will be migrated from SD modeling to ABM then it will show more precise and more meaningful results. Also it is useful to migrate from SD to ABM assignments where there are different kinds of agents with different kind of states that affect each other.

The Figure 7 shows the basic processes for migration from SD modeling to ABM. The most important part for migration a model is to understand who the agent is. Also the other important par for migration is verification and validation of the model. Every model needs to have verification and validation in order to have successfully made simulation model.

Firstly there has to be made a theoretical model of the example SD model. To develop a theoretical model there should be defined model architecture, the main concept of the model has to be understood. The main part is to define the agent. If that part is not correctly done then the whole model can be not correct. Usually agent can be founded more easily if it is possible to find out what represents stocks.

Very often stocks are filled with agents, there just has to be founded out what is this agent. If the agent is founded next part is to define states of agent. In order to better understand agent's behavior, agent has to have states. If the concept of the agent has been defined then there has to be determine what agent's environment is.

Conceptual model has to be so clear that it is easy to make a simulation model after that and in the conceptual model it should be clear what the agent is and all other details concerning it. Before making the simulation model there has to be done verification and validation in order to check if developed conceptual model is consistent with the SD model that has been done before.

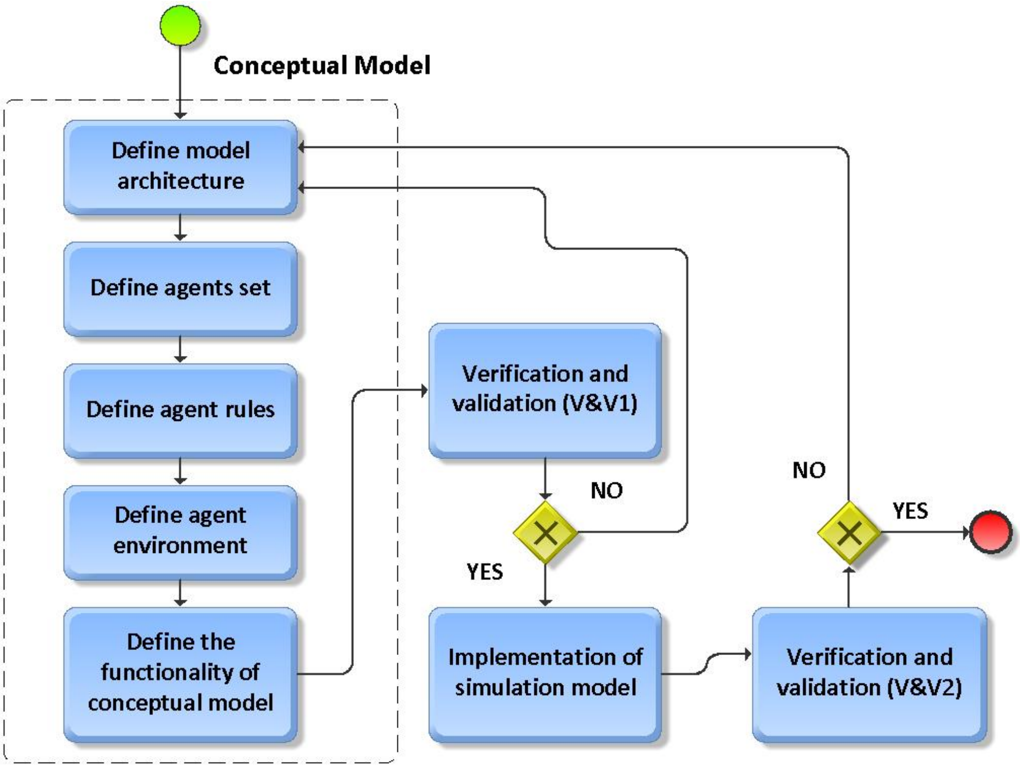

Figure 7: Way of migration from SD to ABM

If conceptual model has done clearly, it can be verified and validated, but after the simulation model can be implemented. In the end there also needs to be another validation to check if developed ABM works exactly as SD model, as well as, is ABM consistent with the SD model.

Verification and validation (V&V1) was done to check if developed conceptual model is consistent with the SD model. Conceptual model was closely compared with the SD model to test if all of the important key points from SD model are added in the conceptual model of ABM and to verify if all of the functionality of SD model is added in the conceptual model.

Verification and validation (V&V2) was done to check if developed simulation model is consistent with the SD model as well as the conceptual model. Developed ABM firstly was compared with the conceptual model. Model output was also closely examined under a variety of settings of the input parameters as well as the model input-output transformations was compared to input-output transformations for the real system to check if it corresponds. Verifying that developed simulation model is consistent, it may be inferred that the model is verified and validated.

4. CONCLUSIONS

If there is needed migrating from SD to ABM then firstly it should be really considered if migration to other modeling approach is even recommended and good for the model. There are some situations when migration from SD to ABM is very time consuming and takes too much resources. The main important thing in migrating model is to define who the agent in the model is. It is the most important thing in model and if that is not correctly defined then whole model could be done wrong. If the agent is correctly defined then rest of the things in model will be easier to figure out.

Each of the simulation approach is the better option for different kind of situations. SD model is more useful in order to make simple model that asks for large amount of data. In these types of tasks using stock as a representative of a whole of something is more useful than making it as each agent separately. ABM will be more useful for modeling more individual tasks. The ABM is able to provide additional and more detailed information over what the SD model can provide.

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