

Towards Full Scale Population Dynamics Modelling with an Agent Based and Micro-simulation Based Framework

Karandeep Singh¹, Mazhar Sajjad¹, Chang-Won Ahn²

¹Department of Computer & SW, University of Science Technology, Daejeon, South Korea

²Department of BigData SW Research, Electronics & Telecommunications Research Institute, Daejeon, South Korea

{karandeep.singh, sajjad, ahn}@etri.re.kr

Abstract— Microsimulation and multi agent based simulation are two popular simulation techniques which give us results that could be related to the real world phenomena. Simulation in general has been an important method for analyzing many phenomena and has been used extensively in modelling and simulating the population dynamics. The usage of these techniques have enabled us to perform various different multi-dimensional policy experiments of the ‘virtual’ population and analyze the impact of those policies. These two techniques are popular but there is a need to build a generalized and full scale modelling of population dynamics which can support simulation of various kinds with millions of agents. There are some differences between the two techniques and also there are some drawbacks. The model should incorporate positive aspects of the microsimulation and agent based modelling and should support simulation of all the demography related aspects.

Keywords—Agent Based Modelling, Microsimulation, Demography, Full Scale Social Simulation, Population Dynamics.

I. INTRODUCTION

Population dynamics deals with changes in the size and age composition of populations, and the various concerned factors concerning those changes. It deals with the effect of various factors such as mortality, health, education, economy, matrimony, fertility, migration, welfare etc. on the populations. Many developed countries of the world have undergone decline in the population growth. Majority of the OECD countries have experienced reduction in fertility levels, with in some cases, the fertility rate dipping below the optimal rate for population sustainability. The recent studies have shown that this decline is temporary and will reverse itself [1], [2], [3]. However, countries like Korea have not experienced this turnaround and low fertility rate continues to be a major concern for the government. The population of Korea is declining with low fertility rate. The 2014 fertility rate stood at 1.21 children per woman, well below sustainable level of 2.08 [4], [5].

To ward off future problems, particularly related with the economy, which will come up if population continues to decline like this, policy makers have begun making changes to incentivize and advertise larger family sizes. The results of these efforts however, have not been satisfactory. Though governments are spending huge amounts of money on various

public policies regarding the public welfare, the output of that spending is debatable. Researchers have tried various techniques to optimize the government spending and optimize the results from the spending.

Simulation and modelling are a good way to solve this problem. These techniques have been used to gauge the behaviour of the population and predict the possible outcome of the policy application. Scientist can create virtual environments and virtual societies to experiment upon. Experimenting on real population is long, expensive and an unethical process.

The factors affecting the population could be classified as micro, meso and macro level. Micro level focusses on individual decision making processes. E.g. what factors affect decisions regarding timing and no. of children a couple would have. Meso level approaches consider individuals as social actors who take their decisions while interacting with people in their relations. E.g. how place of residence could affect no. of children couple would have. Macro level approaches considers effect of cultural and institutional setting on individuals.

Popular approaches for simulation are statistical, microsimulation or agent based models (ABM). Statistical approaches are too general and don't help to solve problems like analysing or prediction. The other two are very useful for obtaining and understanding micro-macro links and outcomes. We will discuss microsimulation and agent based modelling approaches here. The purpose of this paper is to introduce microsimulation and agent based simulation in simplest of terms and clear understanding of differences in these two. It also analyses the drawbacks of these techniques in context of demographic simulations and population dynamics simulations and how we can overcome these in a system which has features of both. The rest of the paper is organized as follows: Section II will cover Microsimulation, Section III will discuss Agent Based Modelling and Section IV discusses about comparison, drawbacks and improvement suggestion to these simulation techniques, section V proposes and explains a new simulation model, section VI is conclusion.

II. MICROSIMULATION TECHNIQUE

A. Microsimulation Process of Simulation

The microsimulation as a technique for socio-economic modelling was pioneered by Orcutt (1957) [6], who identified and represented individual actors in the economic system through a way in which their behaviour changed according to time. The early adoption of this technique for socio-economic modelling was blocked by the limited computer resources and lack of data about temporal behaviour.

This technique is based on a large sample of population (e.g. individuals, households, firms, etc.), treated as a unit. The basic concept is simply to represent the primary basic units with unique characteristics rather than using aggregate counts such as output areas from the census. Often, this is achieved by generating a virtual population to represent imaginary rather than real people using aggregate data. In this manner, particular characteristics are associated with a particular unit or individual, so that the distributions of the simulated population match the real or modelled distributions. This concept can be visualized in Figure 1.

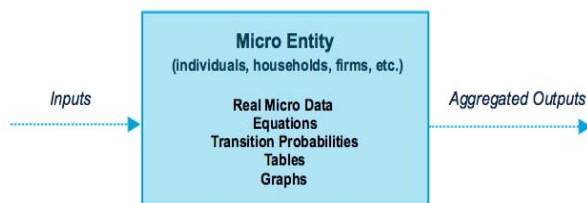


Figure 1. Microsimulation Concept

Once the population has been created in, the model can be used for policy analysis. Various transition rates carry on the simulation and determine the chances that these units will undergo any particular changes as they “age”. Microsimulation is not intended as an explanatory technique, but as a means of predicting the future behaviour. It basically studies and predicts the evolution of a population using a model for individuals. It tries to study in depth the macro consequences of the micro behaviour. Aggregate statistics can be calculated by “adding” up individual outputs and are used as estimates of the future characteristics of the population of the units.

This technique does not attempt to model communication between units, nor attempt to contain the motivations or intentions of the units. There is no interaction between the units of population. A random mechanism process (signifies link to stochastic processes) takes care of the unit “aging” task. There is no feedback from the macro to the micro level. The process of creating individuals based on aggregate data addresses the problem of assigning average group attributes to individual entities, and assuming an ecological correlation between them. Microsimulation are developed with validation ambitions by focusing on the aggregate information of groups of individuals to predict policy impacts [7].

Types of micro-simulation can be defined from a number of perspectives, viz. from types of population, type of temporal variation, case vs. time based etc. Broadly they could be classified as:

Mathematical vs. Behavioural: mathematical models are used for estimating distribution and budget changes while individual behavioural reaction are ignored. In contrast, behavioural model has changes in behaviour according to changes in policies.

Static vs. Dynamic: static model perform analysis for a time point or several pints in time whereas dynamic models update attributes that are defined for each time step with sort of probabilistic algorithm.

B. Microsimulation Demographic Models.

There have been a lot of work done in the field of microsimulation. Micro-simulation has developed mainly in the advanced countries like USA, Canada, UK, Sweden, France, and Australia since 1990's. Some of the famous examples of models are DYNASIM3 (US), DYNACAN (Canada), MOSART (Norway), SESIM (Sweden), SAGE (UK), DYNAMOD (Australia), APPSIM (Australia), DESTINIE (France), and SVERIGE (Sweden). These models have similar structure: initial population, simulation cycle and population outputs. Within each cycle a set of functions calculates the probabilities.

III. AGENT BASED SIMULATION TECHNIQUE

A. Simulation Process Based On Agent Based

Agent Based Models (ABM) can be traced back to Von Neumann [8]. Pioneering examples of ABMs are John Conway's Game of Life [9] and the famous segregation model by Schelling [10]. ABMs basically simulate interactions of autonomous agents in order to study the emergence of global features from the bottom up, the main idea is that interaction can produce the behavior which is more/less than the aggregated sum of the individualistic activities.

Agents in this technique have their own set of rules through which they interact with the others agents and the simulated environment. Agents can access information (sometimes based on past experiences) and make new decisions (signifies link to artificial intelligence). Agents have characteristics like autonomy, heterogeneity, pro-active, reactive, perceptive, bounded rationality, mobility, learning, interactive etc. [11], [12], [13], [14], [15] and many others. The agent based social simulation for demography was pioneered by Billari and Prskawetz [16]. The working concept of agent could simply be stated as shown in Figure 2.



Figure 2. Agent Based Simulation Concept

ABMs agents adapt and react to the ever-changing simulation environment on their own. ABMs' base is a

behavioural modelling and they can easily take feedback effects between micro and macro levels, and for this reason they appear to the ideal complement to the microsimulation models.

B. Demographic Models Based On Agent Based Technique

Many models have been made in agent based simulation. But one of the problem of these agent based simulation models is that they are specific to the problem. Never a generalized agent based model has been prepared. Variety of models have been proposed in demographic context [24], some example are: family formation: Todd, Billari & Simao [17]; Billari [18]; Billari et al. [19], [20]; Hills and Todd [21]; Aparicio-Diaz et al. [22]; E. Frydenlund [23], Migration: Heiland [25]; Kniveton, Smith & Wood [26]; Willkens [27], Residential Mobility: Benenson, Orner & Hatna [28], Household Dynamics: Geard et al. [29]. These models are specific in nature and the high-level framework which brings together various aspects of the agent based simulation is missing.

IV. COMPARISON AND COMBINATION OF BOTH THE TECHNIQUES

A. Drawbacks Differences of Microsimulation and Agent Based Modelling.

We have seen till now that many microsimulation agent based approaches have been in design to model and simulate the demographic processes. But there are variety of drawbacks related with these two approaches. The aim of the simulation should be the predicting and analysing the transition link from micro to the macro. This concept can be viewed as in Figure 3.

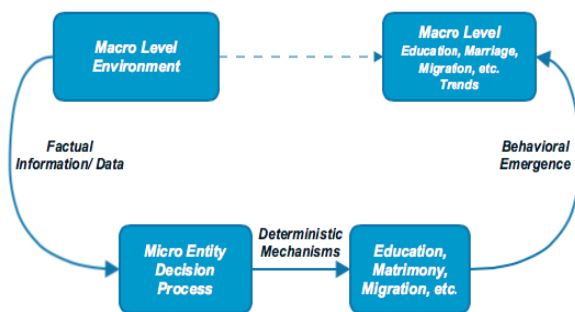


Figure 3. Micro – Macro Link

The basic issue with microsimulation is communication of agents. In models based on this technique, agents don't interact, the simulation consists of repeatedly changing simulated units according to the transition probabilities an adding up the output. The added output would be out of context if agents do interact among themselves. The purpose of the approach is thus, validation, not emergence [30]. This can't be related to reality, especially when we dealing with the demographic and population dynamics processes.

In case of ABM, the initial conditions (individualistic and environmental) are not attempted to be like that of real world. The values are generally taken from the uniform random distributions. This initial choice can affect the output. E.g., emergence of trends from simulation that we can hardly relate to the real world [31]. The requirement to specify all the rules means it is difficult to apply for real world problems.

Table 1 summarizes the differences between two approaches [32]. Important to note here is probabilistic and deterministic rules to move to next 'state'. Probabilistic means a probability that it would move to next state, whereas deterministic means a rule set would be used to arrive to next state. Only if those conditions are satisfied, the transition to the next state would take place. Also worth noting is output form: aggregated output in microsimulation and behavioural emergence after the agent interaction in agent based simulation techniques.

TABLE I. COMPARISON BETWEEN MICROSIMULATION AND AGENT BASED SIMULATION

Characteristic	Microsimulation	Agent Based
Origin	Stochastic Process	Artificial Intelligence
Purpose	Projection/Validation	Explanation/Emergence
Research Approach	Deduction; aggregating individual units	Induction ; behavioural emergence of units
Analysis Method	Infer from aggregate to individual	Infer from individual to aggregate
Applications	Econometrics, traffic modelling	Social simulation
Basic Constituents	Micro units and aggregate entities	Individual agents connected with each other
Possible interaction	2	2+
Constituent unit decision process	Probabilistic	Deterministic
Number of agents	Higher	Fewer
Complexity of agents	Lower	Higher
Communication between agents	No	Yes
Development of Expected output	Built through transition probabilities	Built thorough agent's rule set
Agents Properties	Units with provided data and transition rules	Intelligent agents

B. Inputting Microsimulation Data to Agent Based Modelling

Now a days, emphasis is being laid to add behaviour to the microsimulation and add data to the agent based models. Most of the agent based simulation are started with the

random distributions of the data and initial conditions to start the simulation. Similarly random values are also used for space related distribution of the agents to determine the unmeasured aspects of the agents, and to discover the external factors. A different approach to this can be using the principles of the microsimulation and initializing the simulation with that data. E.g. surveys for initial conditions, derived regression equations for evolution of the variables, and empirical distributions for calculation of the new values.

The choice of the initial conditions can affect the output of the simulation considerably and random initialization of the variables would just produce the erroneous outputs of the simulation. If we are using agent based simulation and initial data from the census, the model would become like agents based microsimulation with all the transition probabilities equal to 1. A hybrid model would contain some deterministic transition rules to generate behaviour like that of agent based model and some probabilistic rules where there is lack of information like in a microsimulation model.

Several efforts have been made for the introduction the empirical data into ABMs. [22], [23], [33], [34], [35]. These examples show how random initialization can be addressed successfully by feeding the model with real data. It is know that the random initialization of data is particularly inadequate in the distribution of the links between agents and to form a social circle or a network [36]. One popular example of the improvement of the ABM model output by introducing data is Eurovision song contest [37].

Feeding the model with the actual data could be particularly helpful in demographic simulation as quantitative & qualitative data is now often collected regularly for demography changes. Some aspects of microsimulation, such as basing the simulation on survey samples and using probability transition methods to determine changes in the values of agent parameters, can be usefully applied to the design of ABM.

Agent-based models usually follow deterministic rules which are event based rather than using transition probabilities. However, the limitations of modelling or the lack of required data frequently make it difficult to implement explicit rules and there is no way out but to other solutions, one of which is to use transition probabilities [38].

Therefore we can move towards the direction of rearranging the modelling steps:

- 1) Design the agent based model.
- 2) Initialization of the model with static data from the census, surveys etc.
- 3) Simulation results.
- 4) Validation of the output results, i.e. comparing the result and the already collected data. This would ensure that model is correct.

The evidence of the better output results by using the real census data can be seen from the Mentat model [38]. The case study of this model revealed the advantages of using the real data for the simulation [39]. Two cases were tested:

- 1) Running model with random initialization.
- 2) Running the model with real data initialization.

The comparison of outputs clearly showed the benefits of real data driven simulation. In short, the data driven ABM simulation was closer fit to real data than the randomised simulation.

C. Towards Full Scale ABM modelling

While taking into account the desirable properties of both the agent based and microsimulation, there is a need to move towards full scale modelling of the population dynamics. There are no generalised frameworks available that can be used by modellers and government agencies to test the policies before its actual implementation. This full scale model could support all the demography related aspects, such as mortality, health, education, economy, matrimony, fertility, migration, welfare etc.; take into account all of these and simulate the society and public policy. This model would support the micro to macro transition by using actual data and also would be able to analyse useful trends while transition is taking place. The number of agents supported should be large in number (to the tune of millions) and it could make usage of techniques such as distributed computing due to its massive scale [40].

V. PROPOSED MODEL

The proposed model is BDI and microsimulation based MAS system. The belief–desire–intention software model (usually referred as BDI) is a software model developed for programming intelligent agents. Superficially characterized by the implementation of an agent's beliefs, desires and intentions, it actually uses these concepts to solve a particular problem in agent programming. In essence, it provides a mechanism for separating the activity of selecting a plan (from a plan library or an external planner application) from the execution of currently active plans. Consequently, BDI agents are able to balance the time spent on deliberating about plans (choosing what to do) and executing those plans (doing it). There is a set of beliefs, i.e. knowledge of an agent about the world and about the other agents. There will be a set of desires; the various goal states an agent want to achieve. The intentions, which is the current goal being pursued by the agent. There would also be a set of plans, or plan library which agent has to achieve the desired goal states. The beliefs, desires and intentions will be updated regularly and could change with the passage of time [41], [42]. The BDI architecture in general can be summarized by the Figure 4.

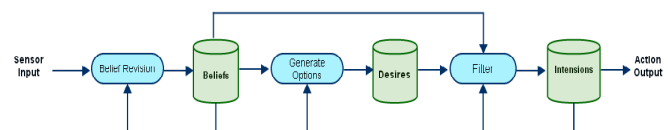


Figure 4. BDI Architecture

Currently, the implementation of the proposed work is already in progress. One of the modules of the proposed work is regarding effect of maternity leave on the fertility. This module is explained here in short, and this would be the basic

approach towards the data collection and simulation. There would be various assumptions, some of them are:

- 1) All the agents in this model are assumed to be married.
- 2) The agents would be generated with distributions of male and female as in actual population.
- 3) Similarly we will take into the actual distributions regarding age, income, type of job.
- 4) These trends would be extracted from the actual data in census data.
- 5) Wherever required data is not available, transition probabilities would be used.
- 6) The initial number of agents could be to the tune of 50,000.
- 7) The parental leave system and associated availing would be taken into account.
- 8) All these factors would be available to the agents for decision making i.e. trends and probabilities from the actual census data and agents would interact and make decision using the BDI architecture explained above.
- 9) We will take into account the parity of women those who avail the leave and those who don't. All the agents in the system would be dynamic in nature. Agents would interact with each other dynamically and update the new information for the further decisions.
- 10) Their decisions would change in the simulation due to changes in job profiles, changes in maternity leave system, with age, with parity etc.
- 11) We will also consider factors like inflation, women participation in the labor force etc. to gauge the economic effect of having children.

The modeling would be done in the Jason Multi Agent System. Jason is an interpreter for an extended version of AgentSpeak, which has been one of the most influential abstract languages based on the BDI architecture. Jason is available Open Source, and is distributed under GNU LGPL [43]. The temporal effect of the simulation (passage of time) can be taken care of by system time ticks, which is fully supported in Jason. Jason multi-agent system can be easily distributed over a network.

The example use case will be Korean population. Data will be taken from KOSIS (Korean Statistical Information Service, 2014). The various trends regarding the childbirth and other associated factors would be taken from the census data starting from 2005. We have chosen 2005 as starting year because of following reasons:

- 1) Fertility rate in Korea was lowest in 2005.
- 2) Fertility rate in Korea has increased after the year 2005.
- 3) There have been major policy changes in maternity leave system in Korea after the year 2005.

The data from 2005 to 2104 would be taken into account. From observing these data we can easily visualize the trends. Figures 5 represent fertility rate, inflation increase and women employment rate respectively.



Figure 5. Fertility Rate, Inflation Rate, Women Employment Rate

As we have already mentioned that major policy changes took place after 2005, we can accordingly see that the fertility rate has risen up. Also we can see that due to increased inflation every year, the opportunity cost to have children is increasing for women. We also see the declining trend in the women employment due to imbalance in work and family life. All the trends and the associated probabilities will be fed into our agent based model, with probabilities associated with each input factor. We also intend to incorporate the agents' impact on each other when they interact with each other regarding the fertility intentions and realizations. The diagram for the overall process can be summed up as figure 6.

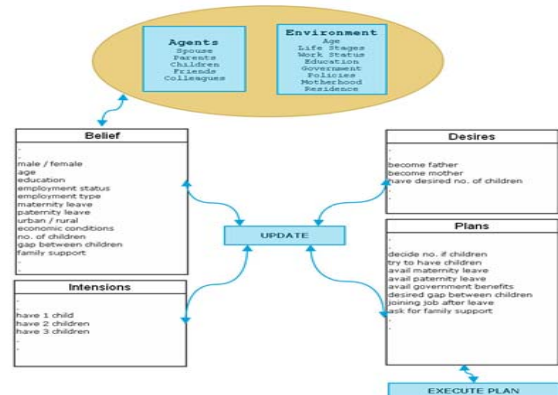


Figure 6. Architecture of Proposed Hybrid Model's Module

VI. CONCLUSION

The demographic transitions, population dynamics due to various factors are important topics in the contemporary world society especially when many countries are facing problems like low fertility. There are a number of challenges faced by scientists in study and analyzing these trends, changes, transitions.

Simulation is an important and useful technique which as aided scientists in observing, analyzing these trends as well as to optimize the government policy to maximize the desired effects of various welfare schemes and policies. This paper introduced micro simulation and agent based simulation and stated essential differences & drawbacks of these two techniques in context of demographic and population dynamics simulations.

Further, we proposed a new model which uses both the techniques simultaneously to achieve micro to macro transition in a full scale general framework, the output of which is close to reality.

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Singh Karandeep, received his Bachelor degree from Punjabi University, Punjab, India and his Master degree from PEC university of Technology, Chandigarh, India. He is currently a PhD student of University of Science and Technology (UST) at Electronics and Telecommunication Research Institute (ETRI), South Korea. His research interest include Social Computing, Big Data Analysis and Cognitive Machine Learning.



Sajjad Mazhar received his Bachelor from university of Peshawar, Pakistan and his Master degree from Dongguk University, Seoul, South Korea. He is currently a PhD student of University of Science and Technology (UST) at Electronics and Telecommunication Research Institute (ETRI), South Korea. His research interest include Distributed artificial intelligence, Social Computing, Complex System, Big Data Analysis and Processing.



Dr. Ahn Chang-Won is a principle researcher at software research lab, ETRI. He is educated on industrial engineering, especially stochastic processes and queuing theory 1998 at KAIST (Korea advanced institute of science and technology) in Daejeon, South Korea and has more than 17 years of experience in SW technologies. Since 2013, he has been leading the ABC-D (Agent Based Computational Demography) project by the demand of ministry of health and welfare, which is to develop a full-scale and flexible ABMS for South Korean population.