

Designing A Multi-Agent Model Using BDI Architecture for Population Dynamics

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Abstract— Multi-Agent System (MAS) is a proven approach that permits to solve large and complex social problems. Due to heterogeneous nature of agents and various variables, many population dynamics problems are difficult to be addressed properly with traditional micro-simulation methodologies. This research work focus the designing of match making and fertility modules of population dynamics. In our model agents interacting with other agents and environment to find a life partner and then take decision about childbirth. The agent's age and socio-economics (referred to as education and income level) conditions are the key factors while taking decisions about family formation and childbirth. Using belief, desires and intentions (BDI) architecture, we explicitly take into account the agent's heterogeneity with respect to age and income level. Designing a conceptual multi-agent model, we are trying to explore how changes in agent's desires and intentions might be transmitted through a population to effect the overall perception while taking decision about life partner and childbirth. The implementation of our model will give more substantial evidence about how and why these attributes can influence the evolution of family formation and childbirth in Korea.

Keywords— Multi-agent system, BDI architecture, match-making, population dynamics, socio-economics

I. INTRODUCTION

The economics crises and job insecurity affected the marriages and fertility dynamics in Korea over the past decades. It is very clear that delaying marriages influences population growth directly. In 1970, 88% of women aged 25-29 in South Korea were married; in 2005 only 40 percent of women in that age group had [1]. Before tying the knot with their ideal partners, they want to achieve career goals, economic stability and more education [2]. Mean age at first marriage for women rose from 24.1 years in 1985 to 28.1 years in 2007. According to the Korea institute for health and social affairs (KiHASA), the rate of unmarried women aged between 25 and 29, which is generally known here as "optimum marriage age" jumped to 59.1 percent in 2005 from 11.8 percent in 1975 as shown in figure.1 [2]. Similarly The TFR (total fertility rate) continued to decline, reaching the lowest level of 1.076 in 2005, but has rebounded to 1.297 in 2012 [3]. According to KOSIS-2014, Fertility in Korea did not decline until the early 1960s, and

during that period the total fertility rate (TFR) remained at around 6.0 or above as shown in figure.2. The decision about the timing of marriage and childbirth has been studied from various perspectives. Psychologists and economists have focused on studying and modeling the process of partner search; micro-level assumptions have usually been at the heart of this approach [4]. Recently, MAS based modeling has been considered as convenient approach to develop models for macro-level marriage and childbirth patterns while generating from micro-level assumptions.

MAS is a collection of heterogeneous and diverse intelligent agents that interact with each other and their environment. The interaction can be co-operative where agents try to accomplish a goal as a team, or competitive where each individual agent tries to maximize their own benefit at the expense of others [5]. We present a BDI based multi-agent model to simulate the evolution of match making and childbirth decision based on agent's age and socio-economic status. The issue of the age and income level is put into perspective in the context of women decisions about marriage and childbirth to study the mechanism that create inter-dependencies among various social characteristics.

Our model based on hypothesis that economic crises and labor market insecurity are the two main factors that effecting the decisions about marriages and childbirth. MAS modeling offers an alternative where we can observe the aggregate effects of decentralized decision making. Our model is trying to investigate those features that may affect the relationship among women's age, and income level.

The MAS based modeling identify the causes of how individual decision making effected the macro-level population. Using MAS based modeling in population dynamics, it is possible to design women agent to be both autonomous and heterogeneous in their decision making about *when* and *how* to take decision about their family formation and childbirth. Individual micro behavior results in a macro outcome that could feedback to the individual decisions. Likewise, micro-macro inter-dependency could be obtained, that can't be modeled in a traditional micro-simulation [6].

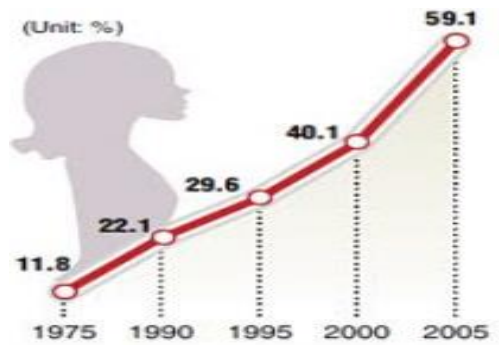


Figure 1. The rate of unmarried women aged between 25 & 29
Source: Korea institute for health and social affairs, 2010

II. BACKGROUND

The literature addressed the impacts of socio-economic status on match making decisions in various aspects. Individual preferences of different characteristics in spouse may also contribute to the probability of marriage [7]. Women's economic participation increases opportunity cost, because working women have more things to lose upon marriage and bearing childbirth than non-working women do. When a woman leaves the labor market for marriage or childbirth, she is faced with human capital degradation, earnings reduction, and other job-related losses [8]. Women with higher educational achievement, higher occupational positions or higher wages may face higher opportunity costs. These women's closer attachment to the labor market reduces their propensity to get married.

Since 1990s, marriage and childbirth are no longer women's universal duties [9]. However, majority of previous research are using traditional analytical and statistical techniques. Traditional microsimulation models building on estimated micro relations have pretty much come to a point where severe problems have risen concerning their ability to actually improve our understanding of behavioral mechanisms and their repercussions on the economy at large [6], [10]. The problem of addressing the late marriages is not simply a matter of predicting that it leads to low fertility, but addressing 'why', which inherently rests on individual choices that cause macro-level consequences. In our model, we are assuming that in today life the economic crises and labor market insecurity have great impact on marriages and childbirth decisions. MAS based modeling offers an alternative way where we can observe the aggregate effects of decentralized decision making.

III. MULTI-AGENT BASED SIMULATION

A multi-agent system composed of multiple interacting intelligent agents within an environment. Multi-agent systems can be used to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Intelligence may include some method, functional, procedural or algorithmic search, find and processing approach. Multi-agent systems consist of agents and their environment. The agents in a multi-

agent system could equally well be robots, humans or human teams. A multi-agent system may contain combined human-agent teams. Environment also can be divided into virtual environment, discrete environment, and continuous environment [11].

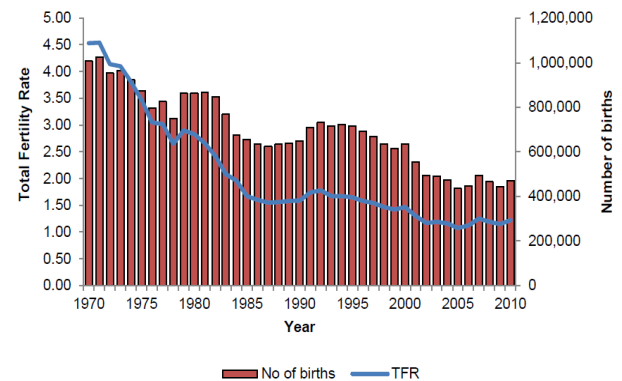


Figure 2. Total fertility rates and the number of births in South Korea, 1970–2010
Source: Statistics Korea (2014)

Each agent has set of rules through which it interacts with the others agents and the simulated environment. Agents can access information (sometimes in light of past experiences) and make new decisions (signifies link to artificial intelligence). An agent is social, interacting with other agents. Agents have protocols or mechanisms that describe how they interact with other agents, just as an agent has behaviors. Common agent interaction protocols include contention for space and collision avoidance; agent recognition; communication and information exchange; influence; and other domain-or application-specific mechanisms as shown in figure.3 [12]. Another point of clarification concerns the term "simulation" Agent-based simulation refers to a model in which the dynamic processes of agent interaction are simulated repeatedly over time, as in systems dynamics, time-stepped, discrete-event, and other types of simulation [12].

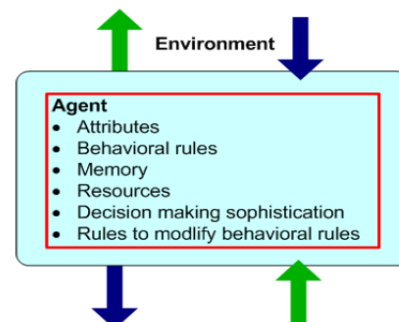


Figure 3. A typical agent behavior
Source: Agent-based modeling and simulation (M.C.Macal, M.J.North)

A. Multi-Agent system with BDI Architecture

Multi-agent systems consist of agents and their environment. The agents in a multi-agent system could equally be robots, humans or human teams. A multi-agent system may contain combined human-agent or teams. Environment also can be divided into virtual environment, discrete environment, and continuous environment [13]. In BDI architectures, decision-making reflects the practical reasoning that we each carry out every day in furtherance of our goals. The basic components of BDI architecture are data structures representing the beliefs, desires, and intentions of the agent [14] shown in figure 3. The Beliefs refer to a set of information that agent has about itself and the environment which may be true/false. This forms informational state of the agent. Desires represent a set of high level objectives and goals that the agent is trying to achieve. Desires must be realistic and not conflict with each other. The intentions refer to the agent's deliberative state in which the detailed sequences of actions, or plans, made to the environment and other cooperating agents through actuators [14], [15].

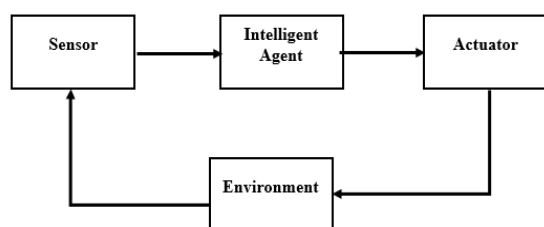


Figure 4. Intelligent Agent interacting with its environment (Naji, et al. 2004)

IV. BDI BASED CONCEPTUAL MODEL

Our conceptual models are designed using BDI architecture. One of the best-known approaches to the development of cognitive agents is the BDI (beliefs-desires-intentions) architecture [16]. Before the simulation begins, a starting population of N agents needs to be created using any BDI development tools like JASON Agent speak, JACK, JADE etc. In order to lessen the complexity of marriage, our model considering only women agents while taking decision for match making and childbirth. All agents have globally accepted age of marriage and childbirth that starting between 16 and 45 that can be assigned randomly or based on some initial census data.

Additionally, in order to reduce the complexity of model, we are assuming that during model simulation agents live in a world where no agent dies before the age of 45, each agent is unmarried, considering her first marriage i.e. no divorced woman, partner will not be in her kinship and considering her first childbirth. As soon as the agent reaches the maximum age of 45 years, it is discarded from the simulation, since her age is over for marriage and childbirth. Income level are randomly assigned based on her education level in order to take decision for marriage and childbirth. The difference in both partners age would not be more than five years. Once the woman give birth

to a child, her fertile period disable for next year. The woman can also set her desired number of children, which may be achieved or not. The agent's various characteristics indicating their behaviours are shown in table 1.

During simulation, agents would be wander around the bounded space, representing a small geographic area, and search for a potential partner based on age and income level. While taking decision for marriage, the potential partners calculate their disposable income after deducting living expenditure and taxes in order to determine if there is enough left over to financially support a household life. Using a yearly time scale, each agents grow one year older within one simulation step. The simulation automatically stops if the population reaches to zero or if 100 years passed. Based on agent's age and combined income, the agents determine whether or not to go for marriage.

Table 1. Agent characteristics for model designing

Agent's variables	Values	Descriptions
Age	16 – 45 years	Indicates the agent's age, considering only eligible agents
Marital-status	Single	Both male and female agents would be single
Childbirth	First	Considering the first childbirth of the marriage
Desired number of children	4	Any agent can set her desired children up to four
Gender	female	Shows agent's sex
Age lower bound	16 years	Agent's minimum age to be eligible for marriage
Age upper bound	45 years	Agent's maximum age to be eligible for marriage
Education level	▪ School ▪ College ▪ University	Indicates agent's education levels

Using BDI architecture, the agent's behavior is represented in the form of beliefs. The agents first make desires for a potential life partner and childbirth. First, in order to fulfill her goals and objectives regarding life partner, the agent making plan and searching for suitable partner based on age and income. After get married, the woman updated her belief and making plan for childbirth. Fixed sizes with various static and dynamics attributes are generated. Our model's beliefs, desires and intentions sample set are shown in figure 3.

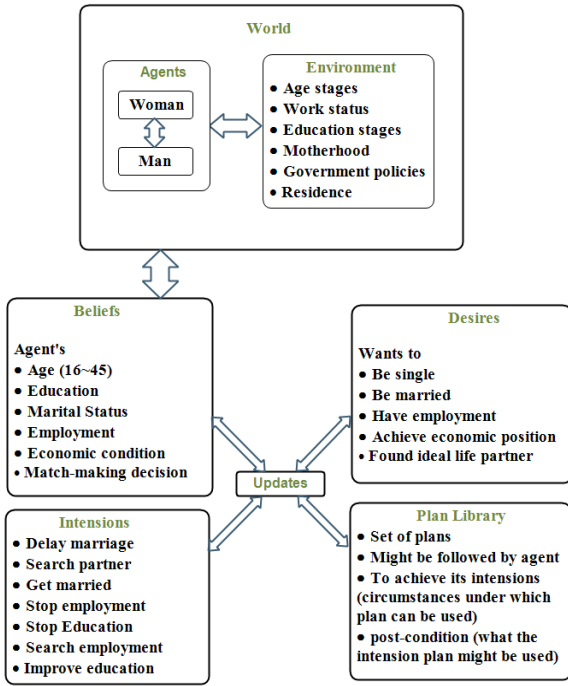


Figure 5. BDI architecture of matchmaking model and childbirth

Based on those beliefs the agents generate their desires for a potential life partner and childbirth decision. The agents make intentions and plans based on set desires. The beliefs, desires and intentions are continuously keep updating based on interactions with other agents and environment as in figure 4 and 5. Unlike real environment, during simulation each agent would marry the very first partner encountered who is acceptable with respect to agent already set desires in terms of age and income level. During simulation the probability for agents to marry increases with time. Because of this increase most agents who find an appropriate mate don't remain single for more than one year. Every agent who finds an acceptable mate gets married with probability p_m shown in equation (1) [17].

Before taking decision for marriage, every agent calculate her disposable income for household life using equation (2) and (3). As long as the income level has not achieved, the agent delaying their marriage for indefinite time. The agent's household income, expenditure and tax are taken from KOSIS (2014) statistics (KOSIS 2014). The equation (1) calculating the probability based on agent's age. The probability is based on agent's current age, minimum acceptable and maximum acceptable age for marriage equation (2) calculates the household disposable income of the agent before taking decision for marriage.

The disposable income would be the remaining income after deducting all kind of expenditures and tax from the regular income. The disposable income must be greater or equal to the median income of the overall population using equation (3). Poor economic conditions at marriageable age with respect to income make potential partners postpone the agent's desire for marriage with the hope to attain better economic condition in future. The better economic condition might be achieved after obtaining high education level that would enabled them to meet

with already set desires. On the other hand to achieve high level education and job search takes valuable time that eventually delaying their marriages.

$$P_m = P_{m0} + (1 - P_{m0}) \frac{a - l}{u - l} \quad (1)$$

$$D_{i,t} = H_{i,t} - (E_{i,t} + T_{i,t}) \quad (2)$$

$$D_{i,t} \geq M_{i,t} \quad (3)$$

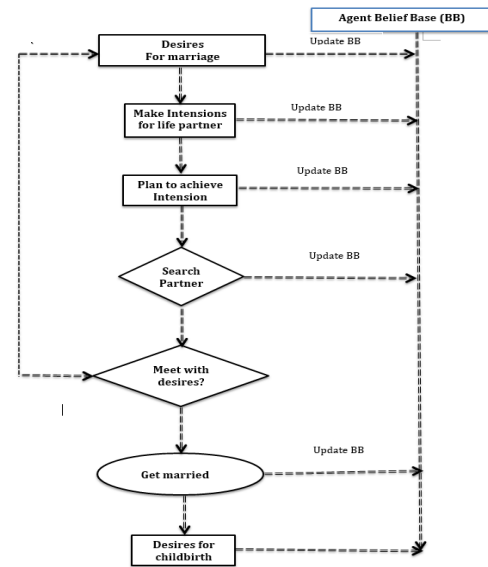


Figure 6. BDI based model flow chart for searching partner

In childbirth model, the fertile period of an agent is from 16 to 45 years. We assume that only married women can give birth to child mean there is no cohabiting state in the context of Korea, every married woman is fertile, all mothers are real, the time spent between the childbirth and actual conception is ignored, the minimum childbirth space is one year, childbirth could be either single or twin and each woman agent has an expecting number desired children, but may not have as many children as expected due to the family economic outcome or other social factors. Before taking decision for childbirth, every agent calculate their combined household income using equation (4) and (5). As long as the income level has not been achieved, the agent delaying their childbirth for indefinite time. The income level is calculated by subtracting household expenditure, new child expenses and regular tax from the household income. The household income must be greater than the median level income of the overall population. The agent's household income, household expenditure, child expenses and tax are taken from KOSIS (2014) statistics (KOSIS 2014). Table 2 below describe all parameters that are using in equation (1), (2), (3), (4) and (5).

$$H_{i,t} = C_{i,t} - (P_{i,t} + D_{i,t} + T_{i,t}) \quad (4)$$

$$H_{i,t} \geq M_{i,t} \quad (5)$$

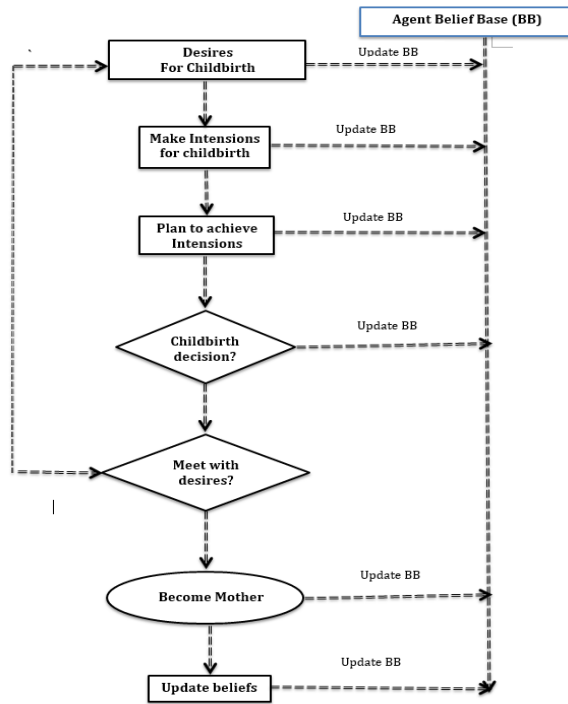


Figure 7. BDI based flow chart for childbirth

Table 2. Numerical parameters and their descriptions

Numerical Parameters	Descriptions
N	Initial population size, $N= 3000$. N agents described by randomly chosen characteristics are created. On the basis of starting population, the evolution of the population is simulated.
a	Agent's current age
l	Agent's lower age limit.
u	Agent's upper age limit.
pm	Probability that an individual who has found an acceptable partner
Pm_0	Probability of marriage in the first year, in our simulation it will be 20% (0.20)
$I_{i,t}$	Agent's disposable income during match-making
$H_{i,t}$	Agent's disposable income during childbirth decision
$C_{i,t}$	Household income
$P_{i,t}$	Household expenditure
$D_{i,t}$	Child expenditure
$T_{i,t}$	Regular tax to be paid

$M_{i,t}$	Median income, this is considered as minimum income for affording married household expenses.
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V. CONCLUSION AND SUMMARY

The MAS based models regarding population dynamics are important topics in the contemporary world society especially when many countries are facing problems like delay marriages and low fertility. There are a number of challenges faced by scientists in study and analyzing these trends, changes, transitions. The study proposed a conceptual MAS based model to represent the match making and childbirth module of population dynamics in Korea. Nowadays, young generations are intending toward late marriages and couples delaying their childbirth, because of mainly financial position and job insecurity. Our model assuming that socio-economic status of the people contributing toward late marriages and delay childbirth. The purpose of our model is to find: how the choices of each individual effect the overall population dynamics of Korea and how these choices contributing toward the late marriages and delay childbirth trends. Our model addressing 'why', which inherently rests on individual choices that causes macro-level consequences. The model will continue to be explored in order to reach the tipping point where some combination of policies could be enacted to turn the match making and childbirth decision making. Additionally, in future we are in the processes to implement our conceptual model and analyse the results. Based on analysis of our result, we are intending to design our model for large scale system, so that we may expect more authentic results from our model. Additionally, social networks and migration factors would add significantly to the applicability of this model to Korean's policy makers struggle towards delay marriages and decline in fertility.

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