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Larry LIN
Singapore Management University, larry.lin.2013@phdis.smu.edu.sg

Kathleen M. CARLEY
Carnegie Mellon University

Shih-Fen CHENG
Singapore Management University, sfcheng@smu.edu.sg

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AN AGENT-BASED APPROACH TO HUMAN MIGRATION MOVEMENT

Larry Lin

School of Information Systems
Singapore Management University
81 Victoria St, 188065, SINGAPORE

Kathleen M. Carley

School of Computer Science
Carnegie Mellon University
Pittsburgh, PA 15213, USA

Shih-Fen Cheng

School of Information Systems
Singapore Management University
81 Victoria St, 188065, SINGAPORE

ABSTRACT

How are the populations of the world likely to shift? Which countries will be impacted by sea-level rise? This paper uses a country-level agent-based dynamic network model to examine shifts in population given network relations among countries, which influences overall population change. Some of the networks considered include: alliance networks, shared language networks, economic influence networks, and proximity networks. Validation of model is done for migration probabilities between countries, as well as for country populations and distributions. The proposed framework provides a way to explore the interaction between climate change and policy factors at a global scale.

1 INTRODUCTION

Human migration is an important research topic, with major economic effects (OECD 2014). At the same time, the decision to migrate is also determined by economic factors (Pew Research Center 2013). This intertwining effect is best captured by agent-based models, where agents interact with their environment, and changes in the environment affects the decisions of agents.

Previous studies on human migration generally make simplistic assumptions about the decision model of migration, or do not consider fluctuations in birth/death rates, age distributions as well as networks ties between countries. With recent economic trends (Grant, Mark 2016), birth policy changes (Buckley, Chris 2015) and climate trends in mind, it is important to develop an agent-based model that is sensitive to these changes. In this work, we developed a country-level agent-based model which aims to mimic the agent's decision-making process for migration. This is done through consideration of a range of country networks, ranging from alliances to linguistic similarities to climate and migrant networks, just to name a few.

Additionally, we initialize the age distributions of countries according to actual data (US Census Bureau 2016). The age distribution is then shifted throughout the simulation through an aging process, as well as actual births and deaths in population. We then validate our model against data for migration probabilities, and country-level observations (population and age distributions). The results are promising, as we illustrate through performance measures such as average of prediction error.

2 MOTIVATION

Our work is mostly motivated by recent trends. Given news on possible major shifts in population (Baer, D 2015), this presents huge opportunities and risks (Baer, D 2015). Also, with international migration contributing to more than half of population growth in developed nations (Population Reference Bureau 2001), it is important to understand the dynamics involved in migration, as well as build models that are able to capture the complex interactions that lead to these shifts in population. Building these models will in turn help policymakers to make better decisions. For this purpose of this work, we do not model domestic migration, as it does not lead to shifts in population of countries, which is the main output of the model that we are developing. We do however, refer to previous work done on domestic migration, and incorporate some of the features into our model, including network externality effects.

The use of an agent-based and other models (e.g., flow-based models) for modeling migration is not a new research topic or area. However, many of them have in place simplifying assumptions, or do not consider a sufficient number of country networks, which we felt led to *less-than-realistic* models, especially if we are looking at migration on a global scale.

For example, (Kennan et al. 2013) developed a comprehensive framework (including cost of moving, pay at different states) on the factors that affects domestic migration. The authors (Kennan et al. 2013) cited data limitations as a reason for working on domestic migration. Such a framework could be used for international migration as well, where economic disparity network between countries would serve as a driver of migration. However, international migration would also require looking at other networks such as linguistic similarities (e.g., English speakers would prefer to move to English speaking countries), which does not apply for domestic migration.

(Smith et al. 2010) looks into rainfall as a predictor of migration decision, as well as network effects such as network peers affecting the propensity of migration. It works well in the area that the simulation is run, where livelihood of farmers is dependent on rainfall, which affects crops. However, we felt that more networks need to be considered if modeling migration at a global level, such as economic networks, where there are stylized facts on more developed nations drawing more immigrations (Population Reference Bureau 2001).

(Dennett 2012) developed a flow-based, spatial-interaction model, which simulates domestic migration as a function of distance between origin and destinations. A distinction between the flow-based model and what we are working is that migrants to a destination are not placed into a common homogeneous population pool. Instead, they are placed into separate sub-populations, in a Origin-Destination Migrant format, where they have a positive network externality effect for future migrants (further discussed in section 3). (Barbosa et al. 2011) came up with an interesting multi-evolutionary agent-based model, where agents undergo a cognitive procedure to migrate given certain age, happiness and wage criterions.

Therefore, considering the strengths and limitations of the previous works, we develop an country-level agent-based dynamic network model that takes into consideration a range of country networks (discussed in Section 3). It is also important to note here that our approach can be replaced with a system dynamics approach, although it would be cumbersome (Gilbert 2008) to model the numerous population stocks involved (discussed in Section 3). Some characteristics of the ABM includes:

- Mesoscopic modeling: contrary to previous works on migration involving microscopic (agents as individuals) or macroscopic (homogeneous population pools within countries) models, we adopt a mesoscopic model approach, where agents are countries, and we model sub-populations within countries, where there are network externalities effect on potential migrants in future. Sub-population here refers to migrants networks, or migrants from country i residing in country j. These migrant networks would have a positive externality effect, thereby increasing the propensity of migrating. This will be further discussed in section 3.

- Heterogeneity amongst agents: Every country has their own migration policies, with differing ”openness” towards immigrants (Line, B. and Poon, L. 2013). While the policies are not publicly available, we used previous migration numbers as proxies for migration policies of countries. These are further discussed in section 3. Every country also has their own age distribution, which is initialized using actual data (US Census Bureau 2016).
- Interactions amongst agents: Decisions made by agents will affect other agents. For example, migration of population from country i to j will alter the age distribution and Origin-Destination Migrant Stock of country j (further discussed in section 3), which has an effect on future migration. For future implementations, we could even look at language distributions (e.g., number of Spanish speaking citizens in a country), and investigate shifts as a result of immigrants arriving at a country.
- Decision Model for Migration: We took into consideration previous works that were mentioned, and modeled the decision to be dependent on several country networks. We believe that this would make for a better decision model, as opposed to only considering climate (Smith et al. 2010) or economy (Kennan et al. 2013) networks.

We believe that this would make for a better model which is sensitive to economic, climate trends, as well as considering other network ties between countries.

3 AGENT-BASED MODEL FOR HUMAN MIGRATION

We developed an Agent-Based Model (ABM) using NetLogo 3D 5.2.0. The interface of the ABM at initialization and during simulation is as shown in Figure 1. Various components of the simulation model are as mentioned in the sub-sections below.

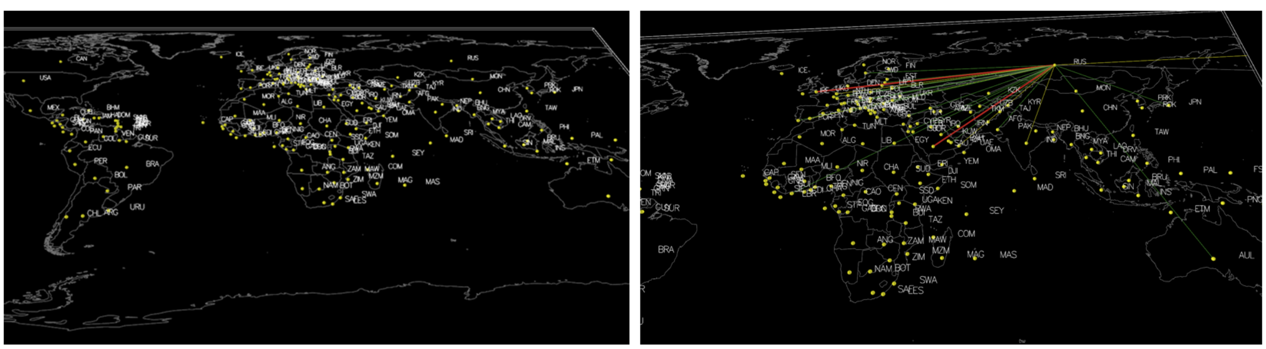

Figure 1: Interface of ABM at (left) initialization and (right) during simulation. Lines colored in red/yellow/green indicate high/medium/low migration numbers.

3.1 Data and Processing

Our core database consists of 194 countries, with static variables such as country name, code, as well as latitude and longitude. Yearly country statistics (e.g., GDP) is obtained from (World Bank 2016) (Index Mundi 2015), as well as official government (US Census Bureau 2016) sites. When data is not available , we will then make approximations based on the indices of ”similar” countries, as well as linear interpolation of data. We made use of data from years 2000 and 2010 (bilateral migration data available) for calibration of ABM, and years 2011 to 2013 for testing.

Table 1: OLS regression results: common language (integer and binary) as independent variable; migration probability as dependent variable.

		$Estimate$	$Pr(<\|t\|)$
Integer	(Intercept)	0.023678	9.55e-07 ***
	$Common.Language$	0.104941	<2e-16 ***
Binarized	(Intercept)	0.027132	2.94e-08 ***
	$Common.Language$	0.100437	<2e-16 ***

3.2 Countries Network

Several types of countries network are considered in this work. These are as discussed subsequently:

3.2.1 Alliance and Hostility Network

For constructing the alliance and hostility network between countries, we gathered data from the Global Database of Events, Language, and Tone (GDELT) (The GDELT Project 2014). Events that occurred between countries are mapped to a CAMEO (Conflict and Mediation Event Observations) scale ranging [-10, 10] specified by (CEDS 2012). The average of these ”interactions” between countries is then converted to [-1, 1] scale, where -1 indicates a negative (hostile) relationship, and 1 indicates a positive (alliance) relationship between two countries. A value of 0 represents a neutral relationship between two countries.

3.2.2 Linguistic Similarity Network

For the linguistic similarity network, countries are tied by their dominant or major languages, and individuals are more likely to migrate to those countries which are linguistically similar. Also, as observed in Table 1, having more than one language in common does not provide better prediction accuracy in estimating the migration probability. The linguistic similarity ties between countries is defined as $CommonLang_{i,j}$, where a value of 1 refers to country i and j having at least one common language, and 0 otherwise.

3.2.3 Proximity Network

A proximity network is computed by taking the distance (computed through the haversine formula) Using the center latitude/longitude of the 194 countries in our core database, a proximity network is developed, with $Dist_{i,j}$ representing the distance (computed through haversine formula) between countries i and j.

3.2.4 Sea-Level Network

For modeling sea-level networks, we used the ”population below 5 meters” data from (World Bank 2016), represented as $PopBelow5m_i^t$, which shows the percentage of population in country i that is below 5 meters in year t. Do note that this data is aggregated at country-level, so for some of the larger countries, there might be disparity in various regions of the nation (e.g., coastal and inland regions), which is not captured here. Each network tie between countries i and j represents the difference in this factor, which is defined as:

$$PopBelow5m_{i,j}^t = PopBelow5m_j^t - PopBelow5m_i^t$$

3.2.5 Economic Influence Network

We used the Gross Domestic Product per Capita of countries (obtained from (World Bank 2016)) as a measure of economic influence, or $GDP_{i,j}^t$, which is formally defined as:

$$GDP^t_{i,j} = \frac{(GDP^t_j - GDP^t_i)}{(GDP^t_j + GDP^t_i)}$$

Where GDP^t_i and GDP^t_j represents the GDP of countries i and j in year t. This economic influence network will then be used to model citizens of countries with lower GDP displaying a higher propensity of migrating to countries with higher GDP (Pew Research Center 2013).

3.2.6 Migrant Network

Last but not least would be migrant network. In the work done by (Smith et al. 2010), the authors developed an ABM whereby an individual is connected to 10 other individuals, and the propensity of migration depends on their networked peers. In our work, we emulate a similar network externalities effect, where increase in migrants from a origin country i residing at a destination j will increase the propensity of others (from country i) migrating to country j. This is formally defined as:

$$ODProportion^t_{i,j} = \frac{OD^t_{i,j}}{Pop^t_i}$$

Where $OD^t_{i,j}$ refers the OD (origin-destination) migrant stock in year t, and Pop^t_i refers to population of country i in year t. $ODProportion^t_{i,j}$ is just the normalized version of $OD^t_{i,j}$. Thus, an example here would be more Mexicans residing in the US will have a positive externality effect on future migrants, increasing the propensity of migrating.

Model-wise, what this means is that when there are individuals from multiple origin countries migrating to a destination country, they will not be placed into a homogeneous population pool. Instead, they are placed into separate sub-populations, and undergo births/deaths, similar to the native population. While the granularity of model is unlike that of (Smith et al. 2010) (with the networks of individuals), these "sub-populations" residing in the destination country create a similar positive externalities effect. The OD migrant stock is initialized with actual data obtained from (United Nations 2015), and updated at every time interval of simulation when migration occurs. Similar to the native population, the OD migrant stock undergoes births and aging.

3.3 Migration Decision Model

For modeling the decision to migrate, we considered various countries networks (as discussed previously). We define the migration decision as $P^t_{i,j}$, the probability of migrating from country i to j at year t, and is formally defined as:

$$P^t_{i,j} = F(GDP^t_{i,j}, PopBelow5m^t_{i,j}, CommonLang_{i,j}, Dist_{i,j}, Alliance_{i,j}, Migrant^t_{i,j})$$

In this work, we take the migration decision to be a linear combination of the various indicators, although it could take on other forms as well (e.g., Logit model). For calibrating the migration decision model, we take the bilateral migration numbers between countries i and j in year t, and express it over the native (non-migrant) population of a country i at year t to obtain the migration probability $P^t_{i,j}$. We currently assume that migrants do not partake in future migration, which we feel is a reasonable assumption, given the time frame we are looking at. Formally, this is defined as:

$$P^t_{i,j} = \frac{Mig^t_{i,j}}{Pop^t_i}$$

Validation of the simulation results will be further discussed in section 4.

Table 2 shows the individual OLS regression results of the decision model, which supports why the individual country networks were selected. For future works, we could perform network analysis such as Multicollinearity Robust QAP (MRQAP) to explore the network effects involved.

Table 2: Individual OLS regression result for migration decision model, with the individual network ties as independent variable, and the probability of migrating as dependent variable. *** indicates significance at the 0.1% level; ** indicates significance at the 1% level; * indicates significance at the 5% level

	Estimate	Pr $(>\|t\|)$
$GDP^{t}_{i,j}$	0.049680	<2e-16 ***
$PopBelow5m^{t}_{i,j}$	-0.09710	4.49e-16 ***
$Migrant^{t}_{i,j}$	1.003172	<2e-16 ***
$CommonLang_{i,j}$	0.116152	<2e-16 ***
$Dist_{i,j}$	-0.215794	<2e-16 ***
$Alliance_{i,j}$	0.069994	<2e-16 ***

3.4 Age Distribution

This is one of the important features of the model. The purpose of the age distribution is two-fold; not only does it help in the validation process (discussed subsequently), it also serves as a way for policy makers to project possible shifts in age distributions of a country.

The age distribution of countries are initialized using actual population and international migrant stock numbers from (World Bank 2016), as well as age distribution figures from (US Census Bureau 2016). Shifts to the distribution are introduced through aging (shift to the right), births (addition), deaths (removal), as well as migration (moved from source to destination country).

The age distribution for all countries are separated into migrants (in blue) and native/non-migrants population (in orange), as illustrated in Figure 2. For citizens migrating to another country, they are placed into the migrant population of the new country, where they do not partake in future migration decision process. This ensures that every citizen migrates only once, which we felt is a reasonable assumption given the time frame (for testing) that we are looking at.

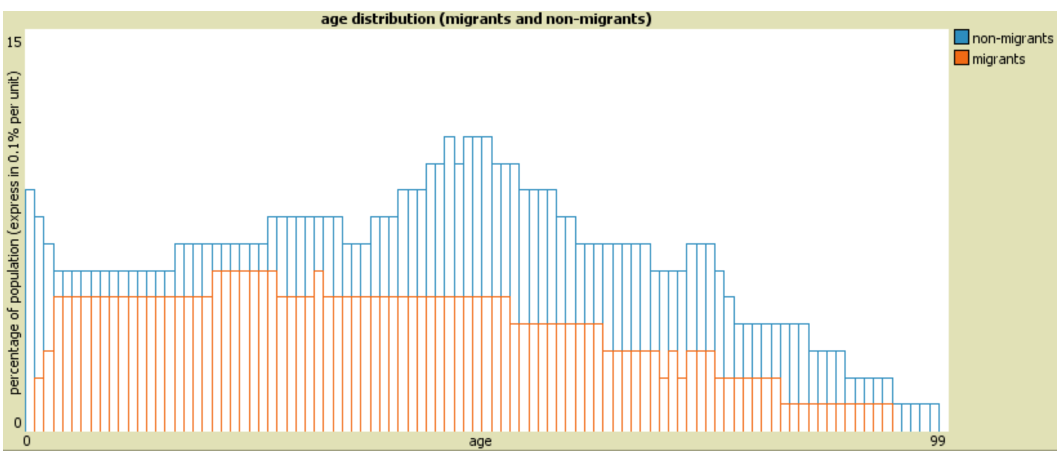

Figure 2: Age distribution for country at initialization. Distributions for migrants and native (non-migrants) are in orange and blue respectively.

3.5 Limit on Migration

As mentioned previously, migration policies vary greatly across different countries. For example, Canada has foreign-born population making up 21.3% of its population, while Japan has a much lower 1.7% foreign-born population (Line, B. and Poon, L. 2013). While exact migration policies (i.e. exact numbers

Table 3: Validation Results: Flow Probabilities between all countries and populous countries. Populous countries refer to top 50 countries by population at initialization.

	Populous Countries	**All Countries**
Average Error	0.037 %	0.057 %
Standard Deviation	0.253 %	1.346 %

allowed for immigrants) are not publicly available, this is an important feature that would make for a realistic ABM. Thus, we used previous bilateral migration numbers and population data as a proxy for the openness of a country towards immigrants. The migration limit for a country j is formally defined as:

$$MigrationLimit_j = \max_t(MigrationProportion_j^t) \ , \forall j$$
$$MigrationProportion_j^t = \frac{Immigrants_j^t}{Pop_j^t} \ , \forall j, t$$

where $Immigrants_j^t$ refer to the number of immigrants arriving at country j in year t.

4 MODEL VALIDATION

Model validation is done by validating the simulated populations, age distributions, as well as the migration probabilities. This is done using average of errors as a performance measure. It is imperative to note that we are not developing a migration prediction model that perfectly fits against historical events. Instead, the focus here is on building an ABMS (Agent-Based Model and Simulation) that is sensitive to real-world trends and the evolution of country networks (mentioned in section 3). It is also worth noting that the data for the less developed countries might suffer from poorer data accuracies (Population Reference Bureau 2001), which might affect the projections for these group of countries.

4.1 Migration Probabilities

For validating the migration probabilities, the actual migration probabilities is compared against simulated migration probabilities. The average of error (AE) for migration probabilities is formally defined as:

$$AE = \frac{\sum_{i,j,t} |P_{i,j}^t - \widehat{P_{i,j}^t}|}{|I| \times |J| \times |T|}$$

where $P_{i,j}^t$ and $\widehat{P_{i,j}^t}$ represents the actual and simulated probability of migration between country i and j at year t.

Table 3 shows the results of validation for migration probabilities between all countries, as well as between the top 50 most populous countries (at initialization). From the table, we can observe that the model is able to capture the migration movement of countries fairly well. Also, noting the better accuracy (lower average error) for the populous countries, this means that the model makes relatively better estimates for the populous countries, which is good, as poor estimates for the populous countries will have a bigger impact as opposed to the less populous countries.

4.2 Population Validation

For validating the simulated population numbers, we will be comparing the simulated population numbers against actual population numbers obtained from (World Bank 2016), and normalize against the actual population numbers. The average of error here is defined as:

$$AE = \frac{\sum_{i,t} \frac{|Pop_i^t - \widehat{Pop_i^t}|}{Pop_i^t}}{|I| \times |T|}$$

where Pop_i^t and $\widehat{pop_i^t}$ represents the actual and simulated population of country i at year t.

Table 4: Validation Results: Age Distribution of Countries, for populations within the age range of 0 to 14 years.

	0 to 14 years
Average Error	2.91%
Standard Deviation	5.47%

Figure 3 shows the average error over time for (in orange) all countries and (in blue) top 50 populous countries. First observation here is that the error increases over time, which is not surprising, due to the compounding of errors (Population Reference Bureau 2001). Also, we can observe that the average error for the top 50 populous countries remains significantly lower than that of all countries over time. This shows the performance of the model in predicting the population, especially for the populous nations.

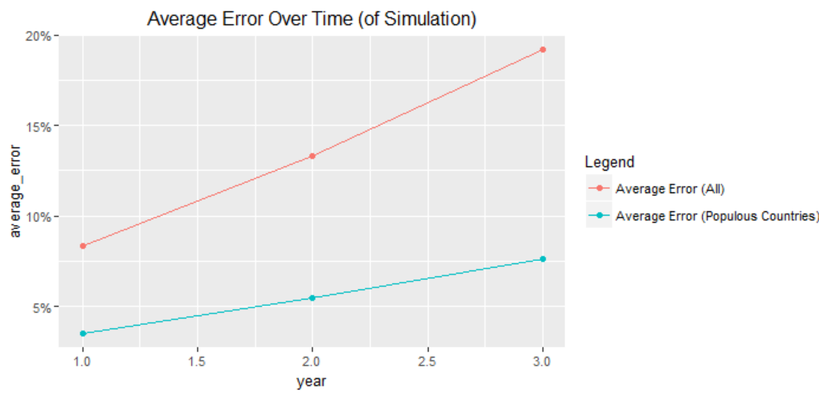

Figure 3: Average Error (Validation of Population) Over Time for (orange) all countries and (blue) top 50 populous countries.

4.3 Age Distribution Validation

Last but not least, we validated the age distribution of countries. As mentioned previously, we initialized the age distribution using actual data obtained from (US Census Bureau 2016), and the age distribution is shifted as a confluence of migration, births and deaths in population. In this case, we validated against the proportion of population within the 0 to 14 years age group (data available on (World Bank 2016)). The average error is defined the same as the average error for country population, except that we now subset the population to those within the range of 0 to 14 years. Table 4 shows the results of validation. This shows that the model performs well in modeling the age distribution, given assumptions of shifts, migration and birth/death rates that we are introducing in the model.

5 STRENGTHS AND LIMITATIONS

In this section, we will discuss some of the strengths and limitations of the model. Strengths of the model include:

- Modeling of network and ties amongst countries, ranging from economy to alliances to linguistic similarities. To the best of our knowledge, no previous work done in simulation of migration has considered such a wide range of country networks affecting migration.

- Simple linear decision model serves as a good starting point for rapid examination of factors affecting population movement, though this could be replaced with other models in future works.
- Age distribution added to allow policy makers to identify shifts in age distributions of countries as result of fertility, mortality, as well as international migration.

Limitations of the model include:

- Data for the less developed nations might suffer from poor data quality (Population Reference Bureau 2001). Thus this might affect the results obtained for those countries involved.
- The migration decision model currently does not consider major events, such as conflicts or war within or amongst countries, which could serve as a driver of migration out of a country.
- The model is more suited for short-term simulation of possible shifts in population instead of simulating over longer period of time. For longer term predictions, it could suffer from poorer accuracies as a result of compounding of errors over time (Population Reference Bureau 2001).

6 FUTURE WORK

This paper discusses the use of the agent-based simulator that was developed, that we have shown to give a good representation of population shifts and migration probabilities between countries. Below is a list of other features and experiment scenarios that we are currently incorporating, which we feel would further increase the realism of the model:

- Modeling of language distributions in countries, which is initialized from data sources (SIL International 2016). As migration occurs, this introduces shifts to language distributions of countries, which would have an effect on future migration. For example, if there are a lot of English speakers migrating out of a country, this might have a negative affect on future English-speakers that are contemplating on migrating.
- Change in migration policies. Countries could change from a open immigration policy (e.g., Canada) to a strict immigration policy (e.g., Japan), and vice versa. Could look into the effects of such as drastic change in policy.

7 CONCLUSIONS

Agent-based models and simulation have increasingly become an important tool for explaining and generating human behaviors. In the areas of human migration, the agent-based paradigm has been used successfully to explain migration movements as a result of climate, economic and peer effects. Our work follows these trends, with a focus on international migration, as we attempt to explain migration and population shifts as a confluence of country networks, along with actual fertility and mortality rates.

The first major contribution of this paper would be the development of country networks that were incorporated into the agent's migration decision model, ranging from alliances to linguistic similarity to economic disparity networks. To the best of our knowledge, previous works in migration do not consider such a wide range of country networks for the migration decision model. We believe that this would result in a more realistic model. The next major contribution would be incorporation of age distributions of countries (initialized with actual data), which is then shifted as a result of births, deaths and migration. The reason for incorporating this is two-pronged; not only does it allow policy makers to identify possible shifts in age distributions, it also allows for additional validation.

Migration is a complex decision which could incorporate various *hard-to-capture* components (e.g., emotional aspects). With the networks that were developed, as well as adoption of the agent-based paradigm, we provided a good explanation of country-level observations (population and age distribution) as a confluence of migration movements, as well as fertility and mortality. Improving the realism of the model remains one of the major research directions in the future.

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AUTHOR BIOGRAPHIES

LARRY LIN is a PhD Student at the Singapore Management University. He received his BSc in Information Systems Management from the Singapore Management University. He is interested in the application of multi-agent-based modeling and simulation in complex business domains. His email address is larry.lin.2013@phdis.smu.edu.sg.

KATHLEEN M CARLEY is a professor in the School of Computer Science in the department - Institute for Software Research - at Carnegie Mellon University. She also has courtesy appointments at Engineering and Public Policy, Heinz School, GSIA. She is the director of the Center for Computational Analysis of Social and Organizational Systems (CASOS), a university wide interdisciplinary center that brings together network analysis, computer science and organization science (www.casos.ece.cmu.edu) and has an associated NSF funded training program for Ph.D. students. Her email address is kathleen.carley@cs.cmu.edu.

SHIH-FEN CHENG is Associate Professor of Information Systems and Deputy Director of the Fujitsu-SMU Urban Computing and Engineering Corp Lab at the Singapore Management University. He received his Ph.D. degree in industrial and operations engineering from the University of Michigan, Ann Arbor, and B.S.E. degree in mechanical engineering from the National Taiwan University. His research focuses on the modeling and optimization of complex systems in engineering and business domains. He is particularly interested in the application areas of transportation, manufacturing, and computational markets. He is a member of INFORMS, AAAI, and IEEE, and serves as Area Editor for Electronic Commerce Research and Applications. His email address is sfcheng@smu.edu.sg.