IOP Conf. Series: Materials Science and Engineering 1203 (2021) 032032 doi:10.1088/1757-899X/1203/3/032032

Probabilistic Modelling of Demographic Changes in Singapore's Neighbourhoods

Malik M Barakathullah[1], Elias Jakobus Willemse[1], Bige Tunçer[1] and Roland Bouffanais[2]

[1]Singapore University of Technology and Design, 8 Somapah Rd, Singapore 487372
[2]University of Ottawa, Faculty of Engineering, Department of Mechanical Engineering, Ottawa ON Canada K1N 6N5

malik_mohamed@sutd.edu.sg

Abstract. Predicting the temporal evolution of the demography and the residents' spatial movements would immensely aid the estate development and urban planning. The evolution of population in three townships of Singapore is simulated at neighbourhood scale using a novel agent-based probabilistic approach with inputs from large-scale survey and statistical data. The demographic changes due to age-dependent rates of death and fertility are studied by considering the inter-ethnic marriages that has a varying probability depending on the ethnicities of the male and female partners. The predicted changes in the age and household compositions and family types have been found to reflect the population trends in Singapore over the past years. The decline in family types that contain children and the structure of age composition over years underline the issue of prevailing low fertility rates. The strategies for incorporating the population relocation to consider the long-term spatial movement are also discussed. In Singapore's context, we consider in the relocation model an added complexity of ethnic quota for the residential units developed by public housing board. The ethnicity dependent parameter coupled with other parameters that represent the number of children in a household besides their size, the household income, the proximity of children's schools, and the places of employment could play a strong role in predicting the spatial evolution of the residents. These predictions can be used by the urban planners and policy makers to improve the quality of life in Singapore.

1. Introduction

The spatio-temporal evolution of the population demography is a process that deserves a better understanding in various contexts such as urban planning, or in preventing infectious diseases [1,2]. The temporal demographic changes in a population are shaped by various events in an individual's life. While the rates of birth, death rates, immigration and emigration affect the global changes in the population within a country, an internal relocation driven by amenities and resources that are required for a normal living causes spatial dynamics.

The evolution of the populations under these events can be modelled either by a dynamical system approach for the unknowns of the sizes of different categories of the population [3], or through the methods of agent-based modelling, where every individual is evolved and interacted to instantiate the events in his/her life with a probability as observed by census data [1]. These models can help the policy makers and planners to visualize various scenarios before their decisions.

In Singapore, over 80% of the population live in public housings. Modelling the demographical changes accurately would help urban planners to plan depending on the various structures of the populations, such as the age and household compositions, and family types. As a feature specific to Singapore, the public housing estates have quotas for different ethnicities of the population — a policy that helps the uniform spatial distribution of these ethnicities countrywide.

The changes in the demography of these public-housing estates of each town need to be predicted for planning the required amenities well in advance. For example, a need for new primary schools in a neighbourhood can be sensed, if the births are predicted to be exceeding the past historical numbers.

In Singapore, the towns have different demographic features depending on their time of developments. For example, a town that is undergoing developments at all periods of time, with some estates being older than the other, has nearly a flat age distribution in the middle-age range, 20–60 as shown in Figure 1(left). We call this type of towns as *Type A*. The towns that contain recently developed estates are more likely to be populated by young couples that have children. In such towns a double peak in the age distribution could be expected as shown in Figure 1 (middle). This type of towns is referred in this text as *Type B*. The earlier the development of a town, more likely they contain aging individuals in households when compared to the towns of type A and B. We categorize such a town as *Type C*. These towns have the age-distribution curve negatively skewed as shown in Figure 1(right).

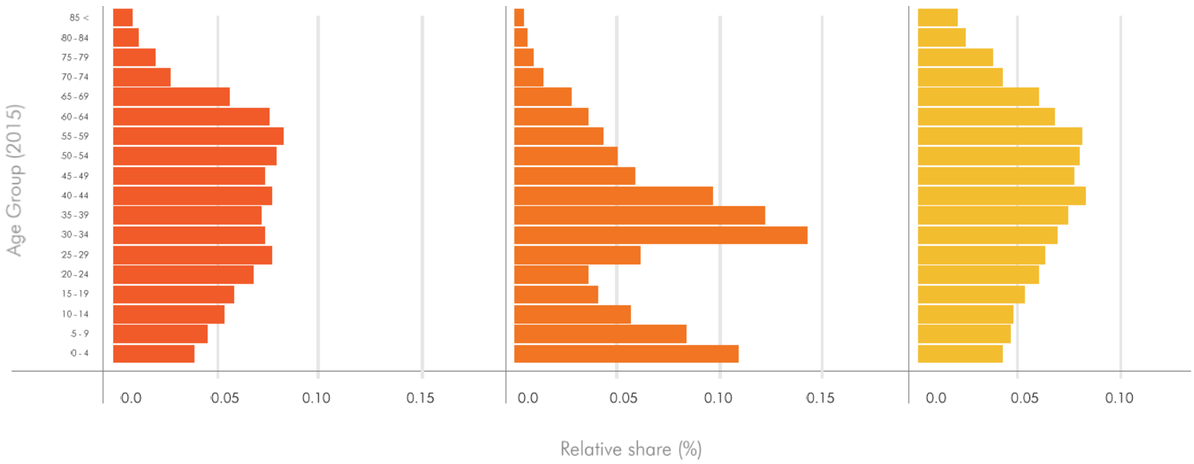

Figure 1. Age distribution of considered types of the towns: (left) Type A, (middle) Type B, and (right) Type C towns. (Source: Department of Statistics, Singapore).

2. Model

For modelling and simulations, we make use of the Sim-Demog model developed by Geard *et al.* [1]. Under this model every individual is represented by attributes — such as, age, gender, marital status, family type, employment status, house ownership, the number of children — that are undergoing temporal evolutions where some of their changes are governed in a stochastic sense with probabilities of the events such as birth, death, marriage and divorce representing Singapore. The model also keeps track of the relationship between individuals, such as husband–wife, or father–son, and so on.

Under the original model, the initial population is generally given by a simulation that synthesise this such that the characteristics of the demography, such as, the age distribution are conformed to the observations found in the census data. However, in the present work we differ by considering the initial population from a large-scale survey which has been conducted in three representative towns of types A, B and C mentioned above. Each of these towns contains several neighbourhoods with their numbers ranging from 6 to 8. A total number of 2580 households were surveyed from all three towns. Though only one respondent participated from each household during the survey, every member of the household as revealed by the respondent are considered in the simulation.

With a time step of a year the events such as birth, death, marriage, divorce and the event of formation of new households after an individual leave their parents' home upon reaching adult age are carried out at the rate of the probabilities given by the census data published by the Department of Statistics, Singapore. The age-specific death and fertility rates used in the simulation are shown in Figure 2. We also consider four different ethnicities people categorised in Singapore: Chinese, Malay, Indian and others. The model has been modified to take into consideration of the inter-ethnic marriage probabilities during the temporal evolution.

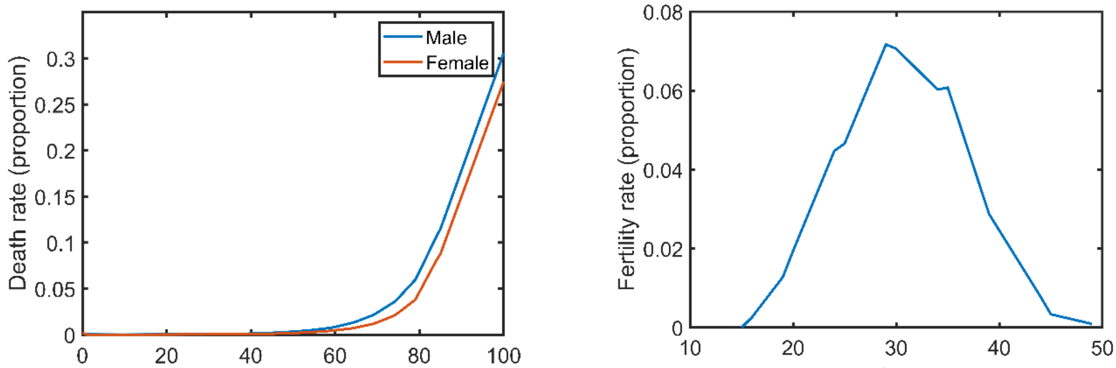

Figure 2. The death rates and fertility rates versus age. (left) The proportion of individuals dying between an age x and x+1. (Right) The proportion of women giving birth in an age between x and x+1.

Table 1. Rates of certain events in the simulation.

Events	Rate
Marriage	0.0374 (annual probability)
Divorce	0.0074 (annual probability)
Adult leaving home	0.0080 (annual probability)
Inter-ethnic marriage	0.1755 (ratio over all marriages)
Single-mother fertility	0.0500 (ratio over all births)

The Table 1 shows the rate of occurrences of certain events. The annual probabilities of marriage and divorce shown in this table are the probabilities of an individual entering into a marriage and leaving it in a year, respectively. In the simulation an adult is eligible to form a single member household without entering into a marriage. The annual probability of such event is shown in Table 1. A five percent of the children are born to single mother as shown in this table. A 17.55% of marriages involve inter-ethnic partners. These probabilities are handled in the simulation using random number generators at every time-step. When such inter-ethnic marriages happen, the ethnicities of the partners are chosen at the probabilities as in the census data of Department of Statistics, Singapore.

3. Results and discussions

The simulations were carried out with the initial population obtained from the large scale survey mentioned above. The demographic changes for a period of 20 years are presented in this section for three towns, where each of them is of type A, B, or C. Though these simulations were performed at the scale of neighbourhood, we have aggregated the results to represent them at town-level. Figure 3 shows the following for a type A town: the distribution of the fraction of the individuals with respect to their age (panel a), the distribution of the fraction of the households with respect to the household size in (panel b), the age composition with respect to the household size (panel c), the age composition with respect to the household age (panel d), the variation of proportions of the family-types over years (panel e), the variation of the proportions of the household sizes over years (panel f), and the proportions of individuals of different age groups in each of the family types. The panels (a) and (b) shows the respective data at the beginning and the end of the 20 years simulation. The panels (c) through (f) show the snapshot of the population at the end of the 20 years simulation.

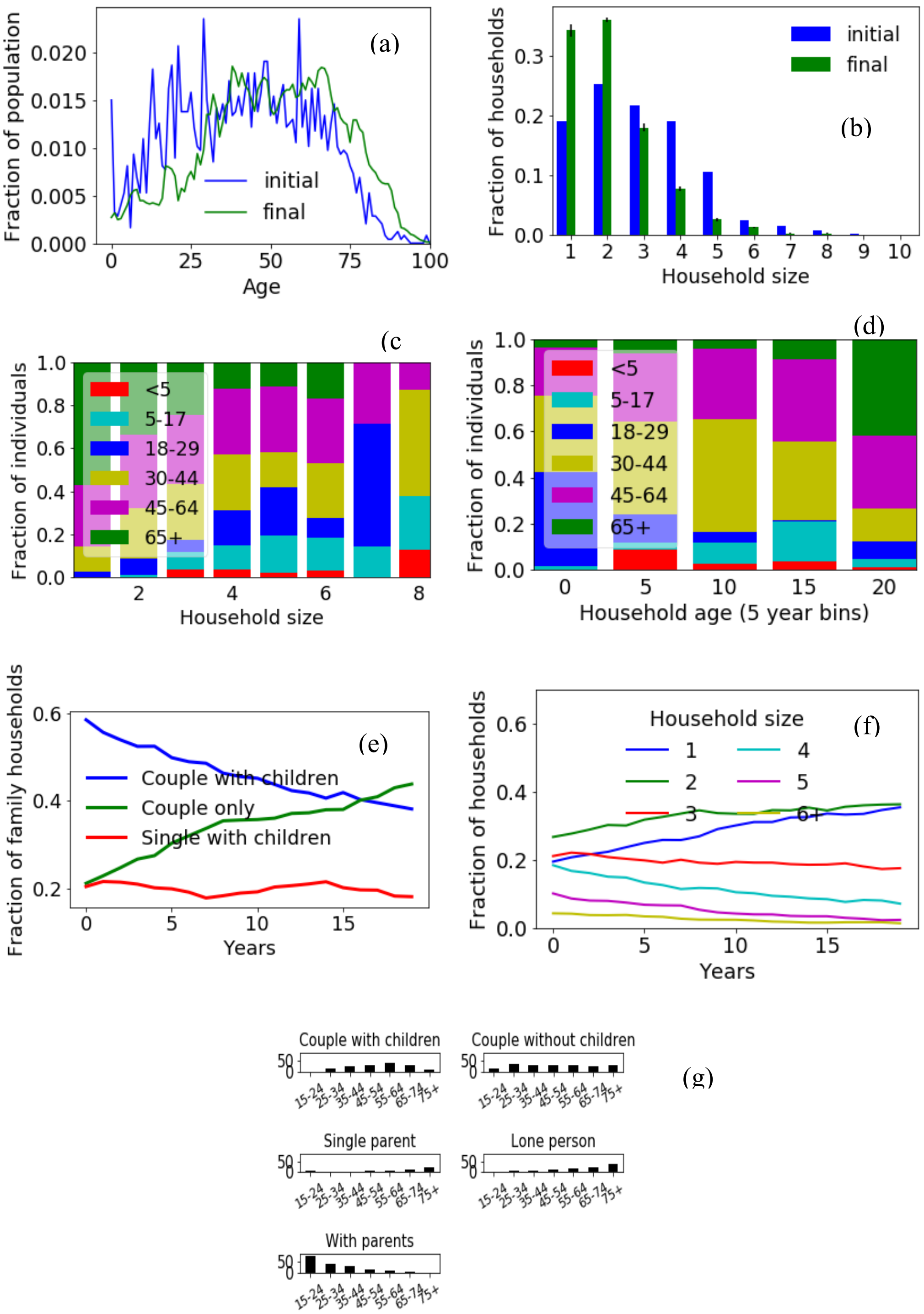

Figure 3. Individual age, household and family-type changes for a town of type A: (a) age-distribution of individuals, (b) proportion of the households versus household size, (c) proportion of individuals of

age slabs vs household size, (d) proportion of individuals of age slabs vs household age, (e) fraction of family households over years, (f) household size versus years, (g) distribution of individuals over different age slabs within each family type.

As can be seen from Figure 3(a), the overall population gets older as years evolve. Figure 3(b) describes that the proportions of the single-member households and that of the couples that are not living with children increase over years, and that the proportions of the households of sizes three or above fall over years. This trends in panels (a) and (b) highlight the fact that the total fertility rate is below the required threshold level needed for a replacement of the population.

The age compositions with respect to the household size and the household age are given in panels (c) and (d). The household age is defined as that start from the time of beginning of the simulation, or from the time of constitution of new household due to marriage between two individuals, or due to the individuals leaving their previous households at certain probability to form a new household when they become adults. The panel (c) shows that the single member households are mostly comprising older individuals of age above 65, and that the young children or young adults are in the households which contain at least 3 members. The panel (d) shows that higher the household age, more likely are they to contain individuals above 65. This phenomenon is caused by the formation new households by member upon marriage or due to the event of leaving home by individuals that form single member households.

The time evolution of the proportions of different types of families of sizes greater than one are shown in panel (e) of Figure 3. It shows that the proportion of the family that contains both partners and children decrease over years, while the households that contains only partners without any children living with them increase. The households that contain single parent and his/her child/children remain without undergoing significant change in the proportion over the years.

The temporal variation of the proportions of the households of different sizes is shown in Figure 3(f). It shows that the households of sizes greater than two drops in their proportions over the years, while the single member households and couples without children living them keep increasing in their proportions during the same period. This phenomenon agrees with the observations made in panel (b). This is, as explained above, due to the low total fertility rate in Singapore, and due to the fact that the children as they grow up tend to form a new household either by marriage, or by forming a single member household at certain probability for this event upon reaching an adult age.

In Figure 3(g), the couple-with-children family type has peak in the age group of 45-55. This can be explained as follows. At this middle age, the individuals have a higher chance of having children born at any previous years. Beyond this age of the individuals, their children start becoming adults and form new households either through moving out as single persons, or through marriages.

Furthermore, younger the individuals, more likely are they to live with their parents as shown in the last sub-panel of Figure 3(g). Similarly, older the individuals, more likely they constitute single member household as shown. Further, older the individuals, more likely are they to constitute single-parent household as shown in Figure 3(g), since there is a higher chance for the death of one of the partners, or for the event a divorce to have taken place in between them.

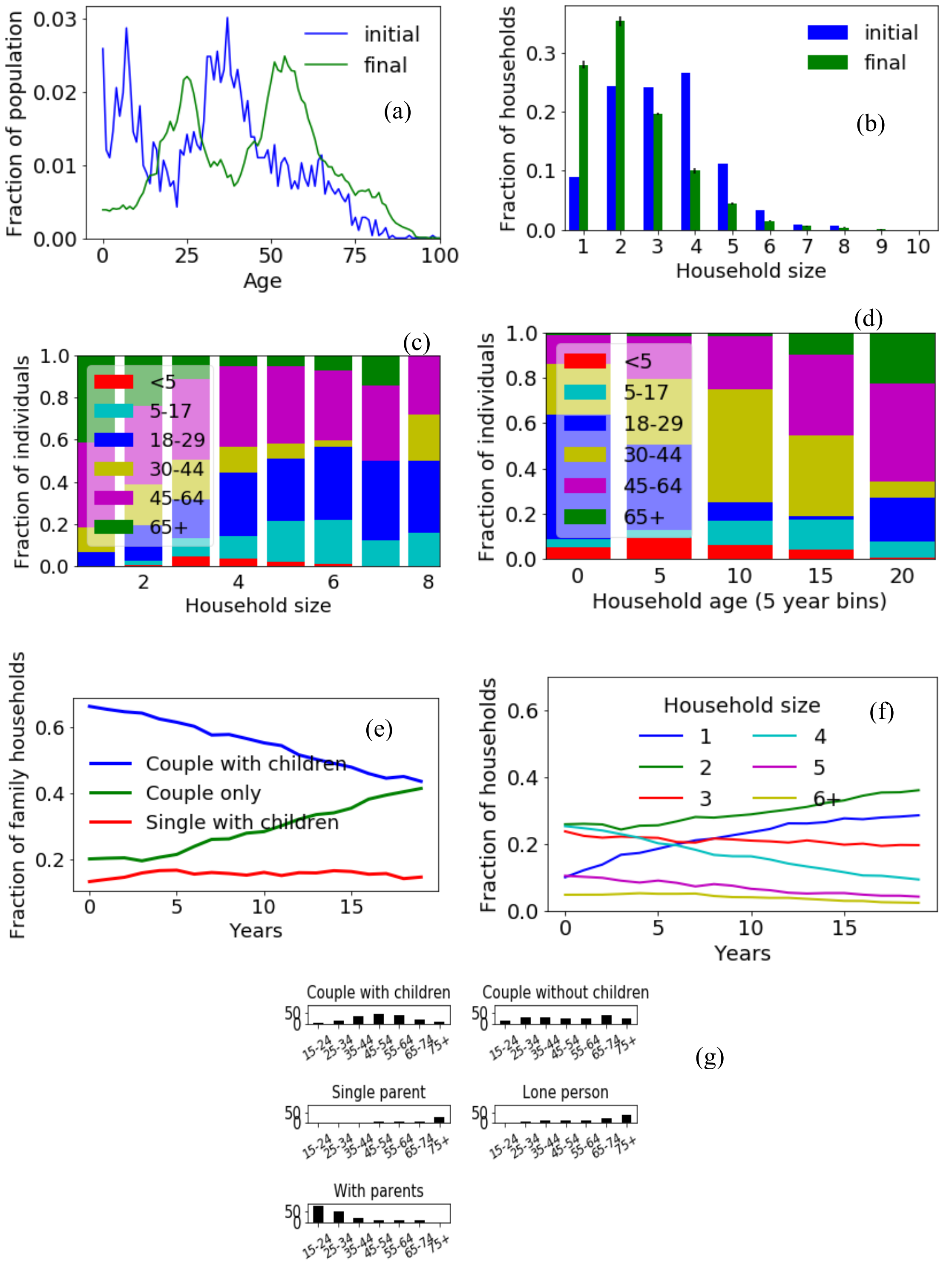

Figure 4. Individual age, household and family-type changes for a town of type B: (a) age-distribution of individuals, (b) proportion of the households versus household size, (c) proportion of individuals of age slabs vs household size, (d) proportion of individuals of age slabs vs household age, (e) fraction of family households over years, (f) household size versus years, (g) distribution of individuals over different age slabs within each family type.

Figure 4 and 5 show the results for types B and C towns, but same as in Figure 3. In Figure 4(a), the age distribution is able to capture the double peaks that we saw in Figure 1, which the characteristic of a type B town. The time evolution is found to preserve this distribution approximately, but shifts to greater ages. The rest of the results in Figure 4 and 5 exhibit good similarity with Figure 3.

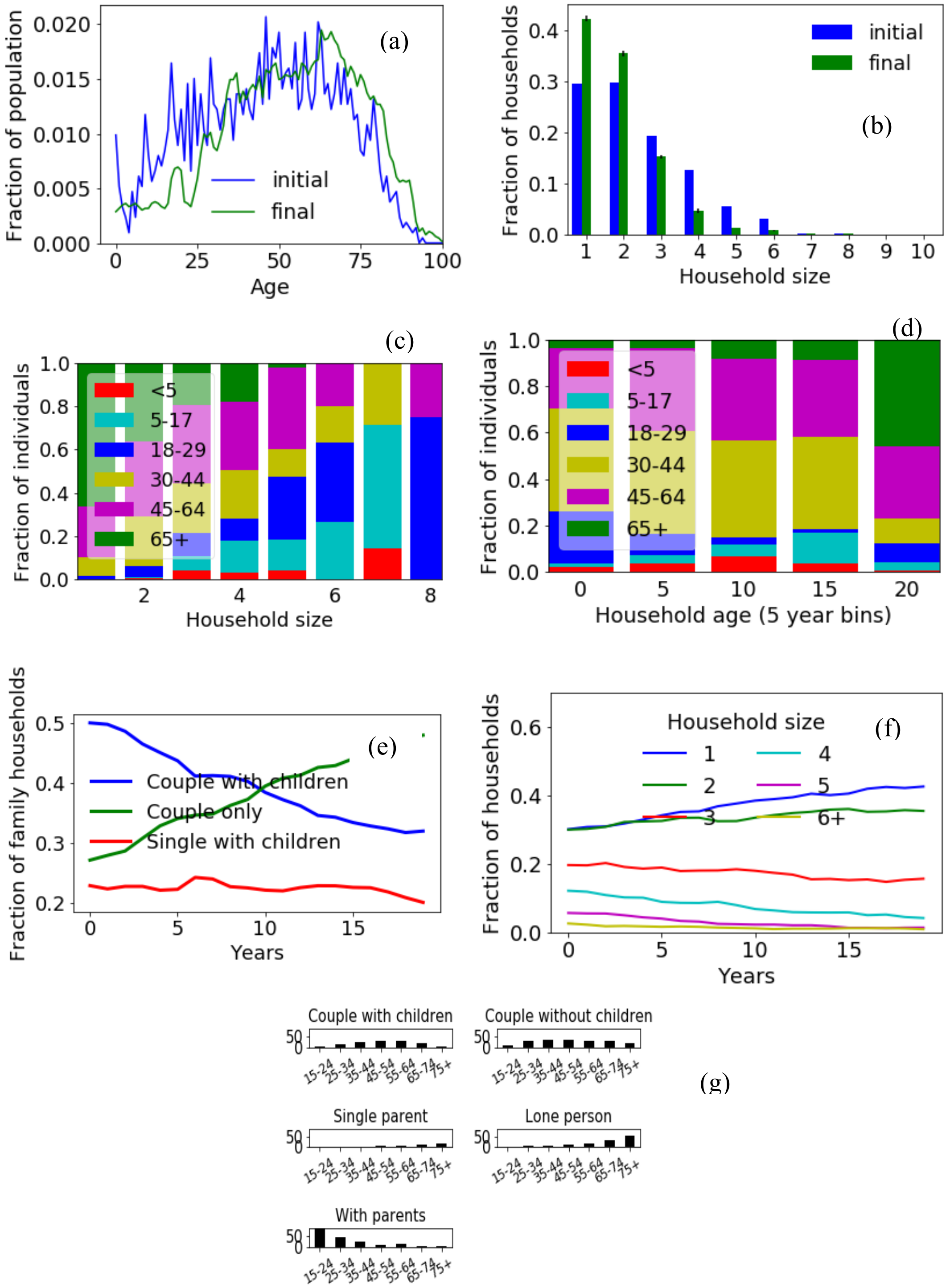

Figure 5. Individual age, household and family-type changes for a town of type C: (a) age-distribution of individuals, (b) proportion of the households versus household size, (c) proportion of individuals of age slabs vs household size, (d) proportion of individuals of age slabs vs household age, (e) fraction of

family households over years, (f) household size versus years, (g) distribution of individuals over different age slabs within each family type.

4. Future direction: relocation model

The demography changes are not just due to temporal events such as birth, death, marriage, divorce and so on considered in the previous sections. The changes due to spatial movements of the residence of the population significantly affect the demography at a chosen location. These spatial movements can be driven by various factors such as the proximities of the places of employment, children's schools, housing prices, individuals' income, and transport facilities. The attributes of the houses such as the number of bedrooms, baths, and sizes of the houses also are parameters in deciding the chance of relocation of a household to a new house. In Singapore's context, the ethnicity quota on public housings needs to be considered to model the ethnicity make up of a neighbourhood more accurately.

For this purpose, we intend to consider the relocation model as described by Waddell [4] as our future direction of study. Under this scheme of Waddell, at every time step of the demographic simulation, the households that require relocations caused by the above-mentioned factors will need to be identified. Further, several alternative options of houses available for purchase by these households will also need to be identified as part of this step of the simulation. The probability of a household relocating to each of the available options is given by discrete choice models, such as multinomial logits. However, the scaling factors that determine the impact of each of the parameters in the above paragraph on the chance of relocations need to be obtained from a statistical fitting on the historical data of past purchase transactions using multinomial logits as implemented in the Python package UrbanSim developed by a group headed by Waddell [5]. Then the relocations are to be carried out based on these probabilities.

5. Conclusion

The demographic changes predicted by agent-based simulation for the three types of towns in Singapore indicate various facts: the proportions of single and two member households increase monotonously with respect to time across all three types of towns. The proportions of the households of size greater than two drops over the years. The distribution of the proportions of individuals with respect to age highlight the issue of low total fertility rate. These facts are also reflected in the time evolution of the family types and household sizes, the variation of age compositions with respect to household sizes and household ages. Across all three types of towns, the proportions of individuals belonging to the family type of couples that are not living with children increase over the years, and the proportions of individuals belonging to the family type that consists of couple only decrease over the same years.

The more accurate demography change will need to consider the spatial dynamics of the residences of the individuals through an appropriate resident relocation model.

Acknowledgment(s)

This research, led together with the Housing and Development Board, is supported by the Singapore Ministry of National Development and the National Research Foundation, Prime Minister's Office under the Land and Liveability National Innovation Challenge (L2 NIC) Research Programme (L2 NIC Award No. L2NICTDF1-2017-4). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not reflect the views of the Housing and Development Board, Singapore Ministry of National Development and National Research Foundation, Prime Minister's Office, Singapore.

References

[1] N. Geard, J. M. McCaw, A Dorin, K. B. Korb, and J. McVernon. "Synthetic population dynamics: A model of household demography." *Journal of Artificial Societies and Social Simulation* 16, no. 1, 2013.

[2] Z. Xu, K. Glass, C. L. Lau, N. Geard, P. Graves, and A. Clements. "A synthetic population for modelling the dynamics of infectious disease transmission in American Samoa." *Scientific reports* 7, no. 1, 1-9, 2017.
[3] N. C. Grassly, and C. Fraser. "Mathematical models of infectious disease transmission." *Nature Reviews Microbiology* 6, no. 6, 477-487, 2008.
[4] P. Waddell. "Modeling residential location in UrbanSim." *Residential Location Choice*. Springer, Berlin, Heidelberg. 165-180, 2010.
[5] P. Waddell. "UrbanSim: Modeling urban development for land use, transportation, and environmental planning." *Journal of the American planning association*, *68*(3), 297-314, 2002.