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Paper title: **Microsimulation modelling of synthetic populations**

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Abstract (200 words):
Individual travellers and households are the basic entities for simulating travel behaviour in microsimulation travel demand models. Whilst it would be desirable to work with an entire population of individuals (or households) within a microsimulation model, a complete state estimation is basically impossible, because some data are systematically missing due to privacy issues. Therefore it is necessary to use alternative techniques, such as the development of a synthetic population, and it is even advantageous to have a synthetic population generator within a microsimulation travel demand model system. This paper gives an introduction to the approach developed for the generation of synthetic households as a sub-model implemented in a microsimulation travel demand forecast model. The approach involves using a GIS model of the study area, which includes dwelling types and locations. The synthetic population (households and individual household members) is generated at the census collector district (CCD) level using ABS census data and the one per cent household sample file data. The synthetic population is assigned in to the available dwellings in the CCD to match the known demographic characteristics of the population. Monte Carlo simulation is employed to generate the synthetic households. The outputs can be presented and displayed in a GIS. The paper concludes with a presentation of the validation results from a study area.

Introduction

With the realisation that activities and activity sequences are important to individuals and households, activity based travel models aim at simulating individual and household decisions with reference to their daily activity and travel patterns. Individual and household are therefore the basic units used in these models, regardless whether they are discrete choice models or microsimulation models, but in particular microsimulation travel demand models.
In microsimulation modelling of travel behaviour, two types of household data are generally required, in terms of household activity and travel diary data and household socio-demographic and economic data. Travel survey data provides detailed activity and travel patterns by individual households, while a study area of households with their socio-demographic attributes are usually derived from census data but by households with aggregated categories. The high cost of collecting household travel survey data has motivated researchers to use other cost effective ways to derive household travel data, such as the development of synthetic household travel data (Greaves and Stopher, 2000, Stopher and Pointer, 2003). The lack of individual household socio-demographic data has encouraged researchers to develop alternative ways, for example, generating a synthetic population as a representative of the study area population.

This paper gives an introduction to the approach developed for the generation of synthetic households as a sub-model implemented in a microsimulation of a travel demand forecast model. It can be seen as a contribution to the small but expanding literature on alternative ways of generating synthetic populations for use in activity-based travel behaviour analysis. The paper begins by a brief introduction to the microsimulation model where the synthetic population sub-model is implemented. After that a summary of synthetic population methods that have been reported by literatures is given. This will then be followed by a description of the approach developed for generating synthetic households. The results of a set of synthetic households for a study area are then presented, associated with the validation results.

A microsimulation model of household travel

Proper consideration of both short and longer term traveller behaviour requires integrated models that reflect a number of choices by individuals and households, including household location, vehicle ownership, destination, mode and route choice. An integrated land use and activity-based microsimulation travel demand forecasting model system may provide a desirable model system to describe these variables, and such a model has been developed by the authors. Figure 1 shows the general structure of this model. Four sub-models are included in the model system: Socio-demographic model, Synthetic Population model, Activity-travel simulator and Network model. In our earlier work (Taylor, Hamnett, Xu and Page, 2002) a separate land use sub-model was included in the model system. The current version of the model uses the land use data as an exogenous input only. The future incorporation of land use data is available in the form of alternative scenarios for the study area, provided by the South Australian state planning agency Planning SA. All these sub-models are loosely connected with each other and can be used independently. The functions of the sub-models are as follows:

- the socio-demographic model forecasts the evolution of individuals and households over time from an assumed base year;
- the synthetic population generator creates a synthetic population as an input representative population for the activity-travel simulator to predict travel demand in a specific study area;

- the activity-travel simulator, which is the key component of the model system, generates activity/travel patterns and forecasts travel demand, as well as scheduling activity and travel demonstrated by individuals and households in time and space; and
- the network model estimates travel movements (including public transport) in corridor networks.

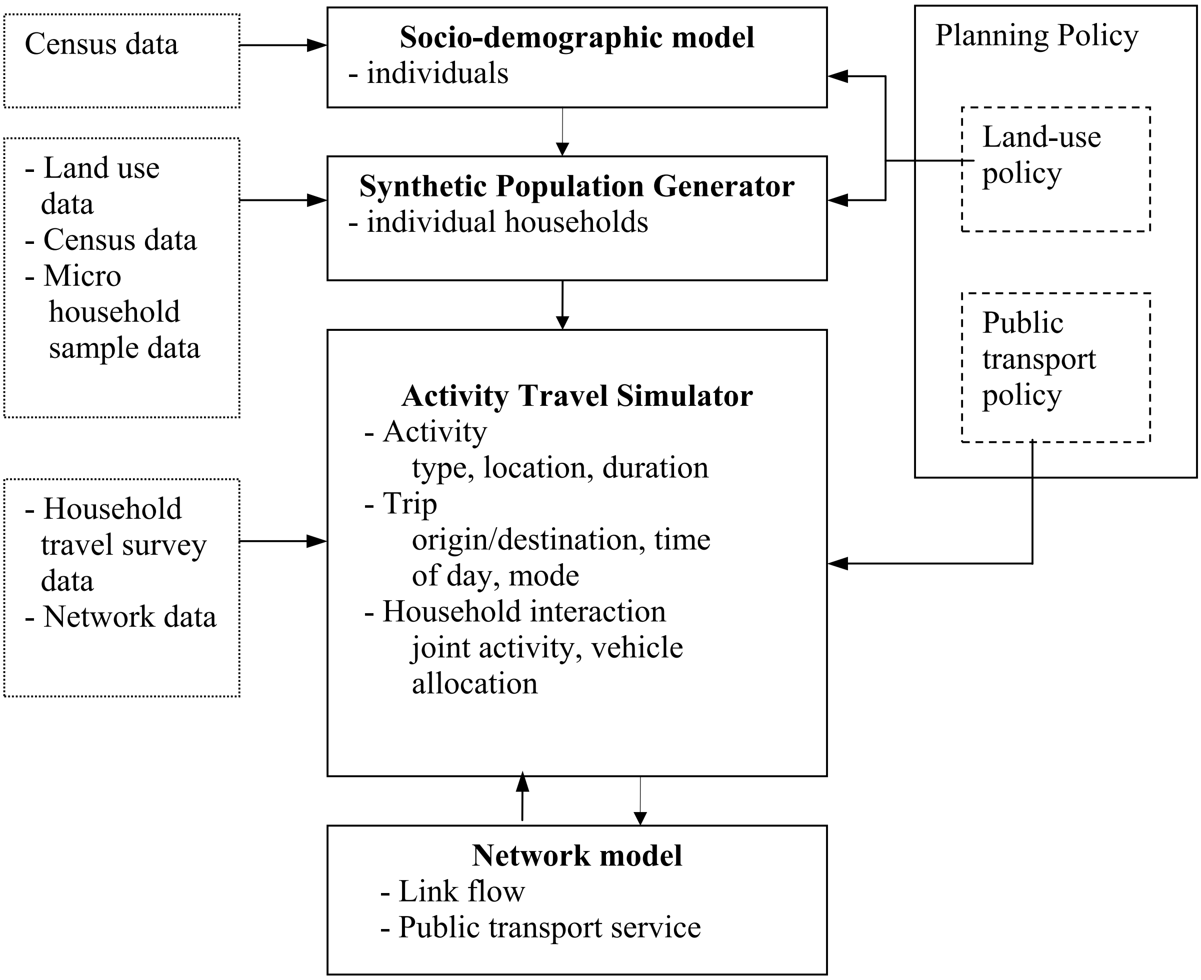

Figure 1 General structure of the microsimulation model system

The fundamental aspect of the model system is that it is an object-oriented paradigm (OOP), developed within the model system, which provides a user-friendly interface for modellers. The Geographic Information System (GIS) is incorporated into the model system and is used as a platform to manipulate all spatial elements without zonal aggregation. It allows for the joint layering of a study area land uses, transportation, vacant land, household locations and household activity patterns. Taylor *et al* (2002) discussed the primary aim of the model development and the factors related to modal choice that require consideration as follows:

> '*the primary requirement of the model is to investigate factors relating to choice of travel mode in the study corridor, with emphasis on the usage of both public transport and non-motorised modes, and to suggest land use and transit service factors that could increase public transport usage (or reduce private motor vehicle usage). These factors could also include encouragement of households with a propensity to use*

> *public transport to take up residence in the corridor. Thus the model is intended to be served as a comprehensive public transport policy analysis tool and also is designed to be sensitive to changes in demographics and land use development patterns in the corridor, and its inputs include alternative land use scenarios representing these alternative situations.*'

To date, the model has been designed to forecast the participation of households in activities/travel in a typical weekday day in a study area, and it is planned to further develop the model to forecast travel demand in several continuing days. The basic process of the model system is to forecast travel demand within a study area using a base year population. The steps required are as follows:

- Step 1: to generate a synthetic population for a study area, the census data, census household sample data and current land use data are input into the synthetic population generator;

- Step 2: the synthetic population data, together with the household travel survey data and road network data are input into the activity travel simulator to forecast schedule activities and travel for each member of a household within the whole synthetic population and to obtain a forecasted travel demand; and

- Step 3: the travel demand data is then incorporated into the network model to estimate the link flow and public transport service requirements.

Any changes in planning policies could be tested by the model by obtaining information on changes in travel behaviour. A change in land use patterns can be included directly into the model, as described in step 1, while travel behaviour affected by any changes in public transport policy would be part of the process outlined in step 2.

The current paper provides a detailed description of the sub-model for synthetic population generation. A more complete description of the full microsimulation model system is provided in Xu, Taylor and Hamnett (2003).

Synthetic population methods

Most of the microsimulation models developed to date, whether for short-term predictions or for medium and long-term forecasting applications, have required a representative sample of population. However, an updating procedure of the representative sample must be included in a medium or long-term application (Miller, 1997). One of the approaches to deal with this is to use a survey sample as the representative of a whole population, such as used in the development of the Activity-Mobility Simulator (AMOS) (RDC Inc., 1995). The basic concept of an alternative approach is to use census data, together with census micro-data sample to generate a synthetic population as the representative of a study area.

Beckman, Baggerly and McKay (1996) represented a methodology for creating a synthetic baseline population of individuals and households which could be used in activity-based travel forecast models. The 1990 census data, the Public Use Microdata Sample (PUMS) and Iterative Proportional Fitting (IPF) were used to create the baseline synthetic populations. Households were generated by a selection of households from the associated PUMS according to the proportions. There were two steps in the methodology. Firstly a multi-way demographic table of proportions was estimated by using iterative proportional fitting.

Secondly, a synthetic population of households was drawn from the PUMS so as to match the proportions in the estimated table. The validation results showed that synthetic populations generated by this procedure possessed no substantial differences from the true values.

Ton and Hensher (2003) reported a procedure for the construction of synthetic households as implemented in TRESIS (A Transportation, Land use and Environmental Strategy Impact Simulator for Urban Areas developed by the Institute of Transport Studies at the University of Sydney). A synthetic household in TRESIS is defined as a household representing a known group of households in a categorized structure by household types and incomes. The approach of the discrete choice models used in TRESIS is different from most others, which segments the population into several subpopulation categories, forecasts average values for the exogenous variables in each subpopulation, and then uses these to calculate the average choice probabilities for each subpopulation After weighting the average choice probabilities by the number of households in the subpopulation, the predictions for the whole population are thus obtained by the sum across subpopulations. Within the model system, three methods, in terms of the mapping method, the uniform distribution method and the normal distribution method can be used to generate a synthetic household by using the input census data and census sample file data. One example of 401 synthetic households were generated to represent an entire population in the Sydney Metropolitan Area, and the comparison results from the census data showed the accuracy of the synthetic households as being acceptable (Ton and Hensher, 2003).

The framework for generating synthetic population

The approach presented in this paper is the synthetic household method. The fundamental notion of the approach was discussed by Taylor *et al* (2002) and Xu *et al* (2003), and it involves using a GIS (Geographic Information System) model of the corridor, which includes dwelling types and locations. The synthetic population (households and individual household members) is generated at the census collector district (CCD) level using the Australian Bureau of Statistics' (ABS) census data and one per cent household sample file data. Detailed land use data are incorporated into the model, including the cadastral database for the study region, which identifies the location and attributes of all dwellings and other building and site developments in the region, by assigning the synthetic population to the available dwellings in the CCD to match the known demographic characteristics of the study area population.

As a sub-model of a microsimulation travel demand, the synthetic population generator has been developed in an OOP environment using Delphi programming software. Monte Carlo simulation was employed to generate the synthetic households. MapObjects was incorporated into the model for data presentation and display within the generator. The outputs in GIS format also can be presented and displayed in GIS software, such as ArcView and Arc GIS.

The process of the synthetic household generation is shown in Figure 2. There are two procedures within this method. The first procedure is the creation of a synthetic population (households and individual household members) at the CCD level. During the first procedure of the modelling process, the generator first reads the number of households in each CCD by their family type and family income, and then randomly picks a household from an appropriate category (family type by family income) in the derived household sample file data, assigning it to a household that has the same category in the CCD. Sampling is done 'with replacement', therefore using the derived household sample file as a set of 'stereotypes' of households. After all the households in each CCD receive their detailed household with their household members, a synthetic population is acquired. The second procedure can then be carried out by the program. According to the available dwellings and their locations and attributes in the input land use data, each synthetic household is selected and assigned to each dwelling. This process is repeated until all households receive their dwellings. When all the synthetic households have been assigned to their suitable dwellings, the households with their dwelling locations can be displayed within the model or in GIS ArcView and Arc GIS for the spatial analysis.

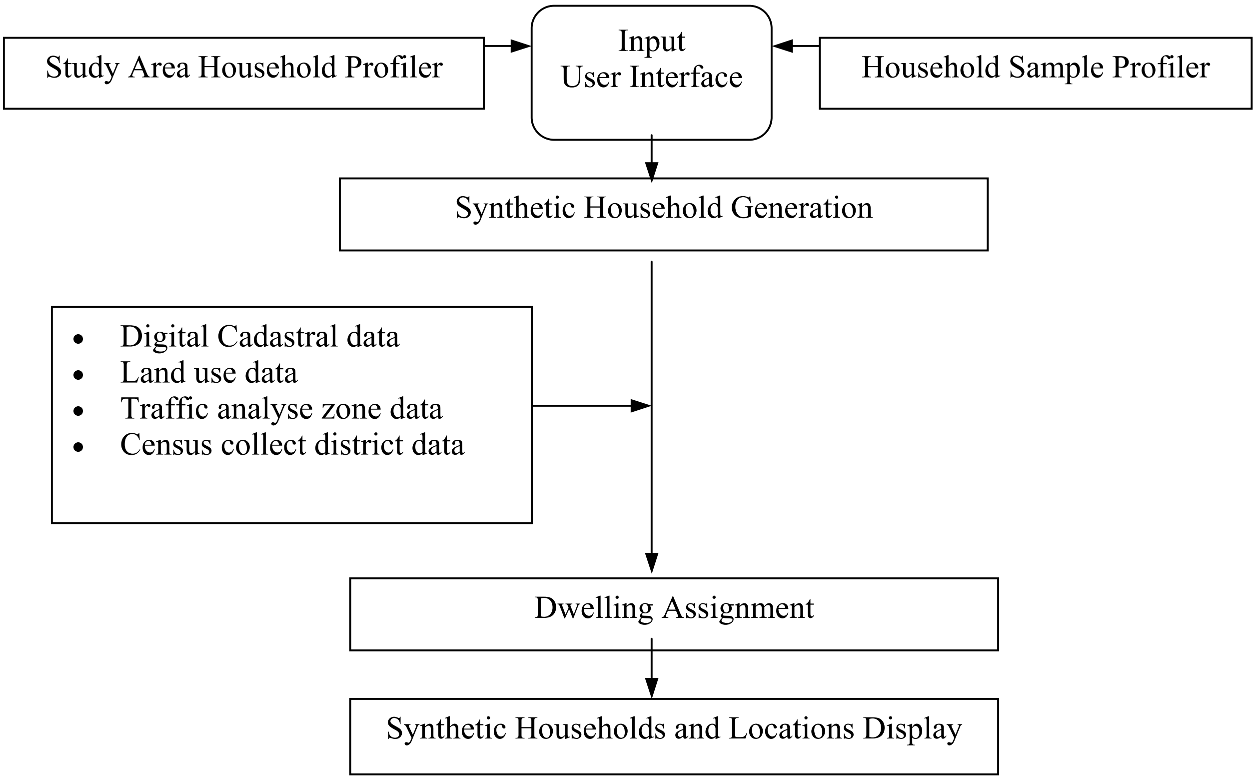

Figure 2 Synthetic Household Generation Process

The data sets

The procedure for synthetic household generation requires a collection of data sets as below:

- Census data
- Census Sample File data
- Digital Cadastral Database
- Land Use data
- Traffic Analysis Zone data
- Census Collect District data

The 1996 Census data

Travel behaviour and activity patterns may well differ by the different characteristics of the households, for example, activities participated by a lone person household would differ from those by households with children. Therefore, it is important to divide households into different categories to examine the travel behaviour and travel patterns in activity-based travel demand models. To do this, three types of households - family households, non-family households and group households are segregated, and synthetic households can be generated respectively. Family households comprise of households with two or more related persons, and are further classified into adult couple family households and adult single parent family households. Households with persons living alone or non-related persons living together are categorised as non-family households. Persons living in dwellings such as college dormitories and hospitals are classified as group households. In this paper, the generation of synthetic family households is introduced by using the 1996 census data, together with the 1996 census household sample file data.

The socio-demographic variables of households, in terms of number of cars, number of workers and number of persons of the household are used to construct synthetic populations within each family household type. The tables that relate to these variables were extracted from the 1996 census data, they include:

- Family type by weekly family income
- Household type by family type by number of car
- Household and family type by number of person
- Dwelling structure by household and family type

According to the census data, family households are categorised into 15 classes, as follows:

- Adult couple only
- Adult couple family with children 0-14 and independent children
- Adult couple family with children 0-14 and dependent students 15-24
- Adult couple family with children 0-14 and dependent students 15-24 and independent children
- Adult couple family with children 0-14 only
- Adult couple family with dependent students 15-24 and independent children
- Adult couple family with dependent students 15-24 only
- Adult couple family with independent children only
- Adult single parent family with children 0-14 and independent children
- Adult single parent family with children 0-14 and dependent students 15-24
- Adult single parent family with children 0-14 and dependent students 15-24 and independent children
- Adult single parent family with children 0-14 only
- Adult single parent family with dependent students 15-24 and independent children
- Adult single parent family with dependent students 15-24 only
- Adult single parent family with independent children only

The number of total households, total households by number of persons (2 persons household to 6+ persons household) by their family income, and total households by number of cars (0 car to 4+ cars, and car not stated) from each CCD were obtained. Summary statistics obtained from the census data for the study area are illustrated in Table 1 and Table 2. Table 3 shows an example of the total number of households by couple family with children 0-14 by income for part of the study area CCD (As there are 337 CCDs in the study area, the table shows a sample of CCDs, for illustrative purposes only).

Table 1 Total number of person per household by adult couple family

	Number of persons					
	2	3	4	5	6+	Total
Adult couple only	15238					15238
Adult couple family with children		6284	7245	2846	1056	17431
Adult single parent family with children	3684	2100	736	267	92	6879

Table 2 Total number of car per household by adult couple family

	Number of cars						
	0	1	2	3	4+	NS[1]	Total
Adult couple only	1236	7928	5038	534	78	424	15238
Adult couple family with children	406	4350	8529	2762	984	400	17431
Adult single parent family with children	1354	3518	1369	312	64	262	6879

NS[1]: Not Stated

Table 3 Total number of household by adult couple family with children 0-14 only by income

	Income								
CCD	Neg /Nil	\$1-\$299	\$300-\$499	\$500-\$699	\$700-\$999	\$1000-\$1499	>= \$1500	NA[1]	Total
4100101	0	0	0	0	0	0	0	0	0
4100201	3	3	10	13	12	10	3	3	57
4100202	3	0	3	5	7	3	0	0	21
4100203	0	3	6	7	13	4	0	0	33
4100204	0	5	7	4	7	4	0	0	27
4100205	0	0	15	7	6	4	0	3	35
4100206	0	3	10	14	9	6	0	3	45
4100207	0	0	5	6	5	0	0	0	16

NA[1]: Not applicable

The 1996 Census Sample File Data

The 1996 Census household sample file data consisting of a one per cent sample of both private and non-private dwellings is a disaggregated data set, with the information of socio-demographic of households to represent the whole population. It is the only data set available to obtain detailed characteristics of households as basic sample households (with their members) data for creating a synthetic population. Considering that the sample size of the study area in the one per cent sample file is small, a whole Adelaide sample with 10,690 records was extracted from the file used for this study.

The data was separated into three different household files according to the 1996 census data. They were family households, group households and non-family households. In family household type, the households were then processed further into 15 categories as discussed in the 1996 census data above. Each category was then again classified into eight small groups according to the weekly family income, these are:

- Negative/Nil income
- \$1-\$299
- \$300-\$499
- \$500-\$699
- \$700-\$999
- \$1000-\$1499
- >=\$1500 and
- Not Applicable income

Variables in each household include the number of cars, number of workers, number of persons, and age of the head of the household. Each sample household also has its family associated with an ID number. Households in the same group are placed in the same file, and these files are formed into a database in Access as input data for generating synthetic households.

The demographic characteristics of the sample data are a little different from those observed in the study area in the 1996 census, as it was extracted from the whole Adelaide metropolitan area. To reduce the possible bias and to correspond with the observed characteristics, an adjustment was applied by putting weights on the household sample data according to the characteristic of the study area population from the census data.

Traffic analysis zone data, census collect district data, digital cadastral database and land use data

Zones are necessary and important elements in a microsimulation model's spatial data management system (Miller and Salvini, 2000). One main reason is that input data; for example, individual households, employment places, and activity places, etc, are all easily accessible at the zone level. The second reason is that the output results can be more easily explained at the zonal level and displayed straightforwardly within a GIS system. In the developed microsimulation model, two basic zone sizes, the Traffic Analysis Zone (TAZ) and the CCD, are required for the analysis of travel behaviour. The TAZs are used to identify trip origins and destinations and the CCD zones are used to recognise the zones where households reside. The digital cadastral database and the land use data are used to identify dwelling types and locations, and other buildings, such as industry, education and retail sites, as well as new development site.

The Synthetic Population Generator Interface

The synthetic population generator was developed in an OOP environment, which has a user-friendly interface to a modeller for easier manipulation. The main interface of the generator is shown in Figure 3. There are three buttons, called *Run*, *AssignD* and *DisplayD*. The *Run* button carries the first procedure of generating synthetic households. Upon clicking the *AssignD* button, a dwelling assignment interface will appear on the screen as shown in Figure 4, and the *AssignD* button in this interface carries the second procedure of assigning households into their suitable dwellings in each CCD. While clicking the *DisplayD* button on either interface, the interface of dwelling display will come into view on the screen, as illustrated in Figure 5.

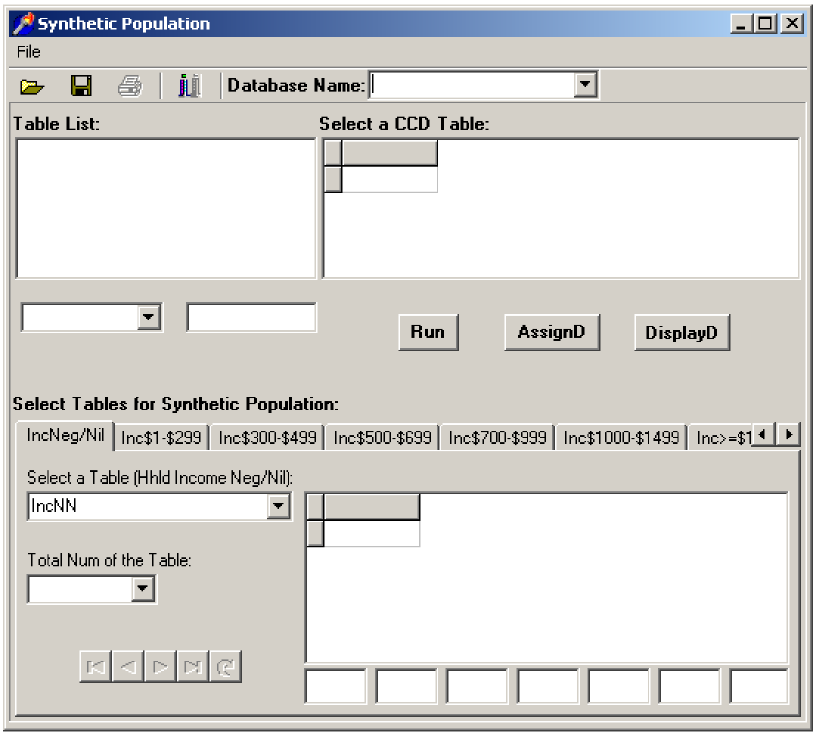

Figure 3 **The interface of the synthetic population generator**

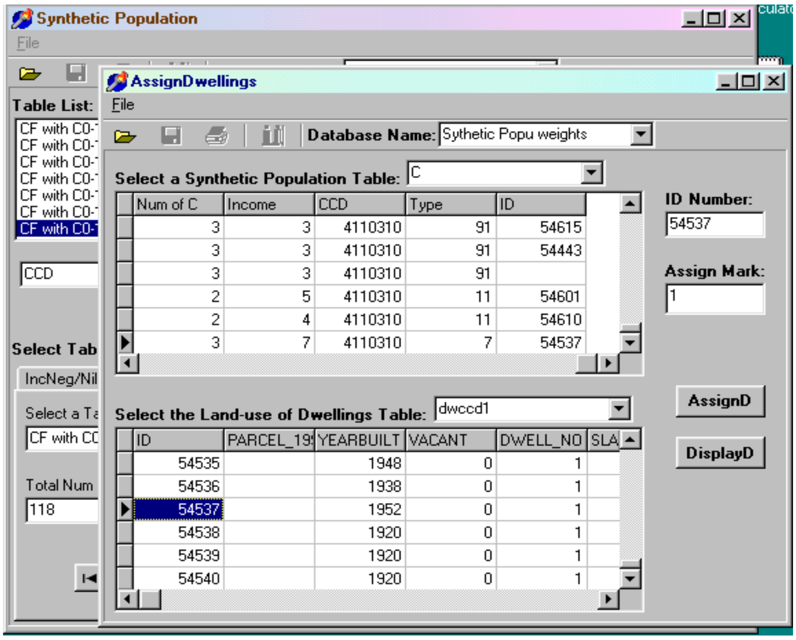

Figure 4 The interface of the dwelling display

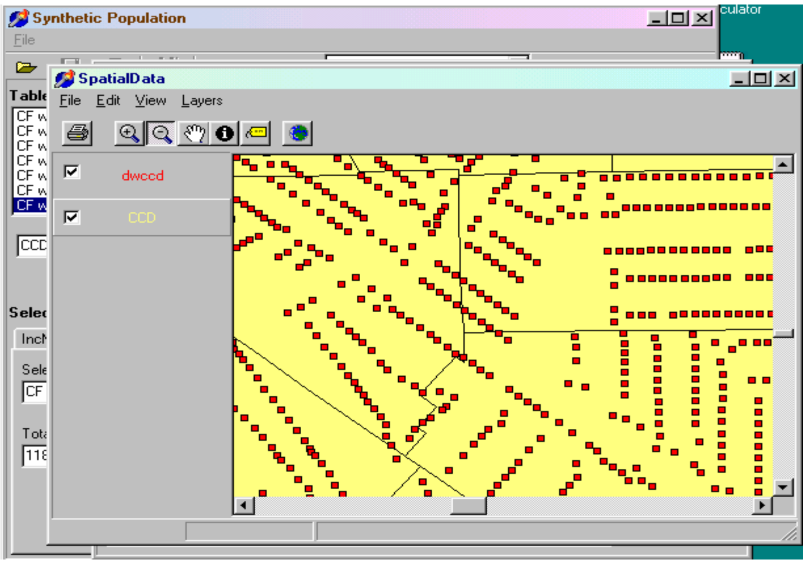

Figure 5 The interface of the dwelling display

Validation

For effective use of the model, several different synthetic populations were sampled, to allow validation of the model with observed behaviour. Each synthetic population may be regarded as an independent sample of the real population.

In this paper, the results from the synthetic households of adult couple families are presented. Ten sets of synthetic households were sampled respectively for adult couple family with children, adult couple family without children and adult single parent family. The Chi-square goodness of fit test was used to test each set of synthetic households with the observed characteristics of the population, in terms of the number of cars and the number of persons by the family type and family income. Tables 4 and 5 show the results of the goodness of fit test in terms of the number of persons between the observed and synthetic population by adult couple family with children and adult single parent family with children. Tables 6 and 7 present the results of the goodness of fit test in terms of the number of cars between the observed and synthetic population by adult couple family with and without children and adult single parent family with children respectively.

All the Chi-square goodness test results are below the five per cent critical value, except for one result from the test for number of cars between the observed and synthetic population by adult single parent family with children (Table 7). The results show that the synthetic households are representing the study area population well as they have similar characteristics with the observed households.

Table 4 Results from goodness of fit test by number of persons in the population by adult couple family with children

	Number of Persons					
	3	4	5	6+	Total	Chi-square χ^2 (3 dof)
Observed	6284	7245	2846	1056	17431	
SynHhld1	6298	7244	2875	1014	17431	2.00
SynHhld2	6380	7182	2847	1022	17431	3.11
SynHhld3	6346	7204	2809	1072	17431	1.57
SynHhld4	6383	7194	2795	1059	17431	2.84
SynHhld5	6361	7277	2775	1018	17431	4.22
SynHhld6	6431	7125	2845	1030	17431	6.07
SynHhld7	6369	7223	2840	999	17431	4.31
SynHhld8	6281	7265	2836	1049	17431	0.14
SynHhld9	6371	7165	2857	1038	17431	2.44
SynHhld10	6316	7148	2913	1054	17431	3.04

Five per cent critical value of χ^2 with three degrees of freedom is 7.81

Table 5 Results from goodness of fit test by number of persons in the population by adult single parent family with children

	Number of Persons						
	2	3	4	5	6+	Total	Chi-square χ^2 (4 dof)
Observed	3684	2100	736	267	92	6879	
SynHhld1	3672	2169	682	271	85	6879	6.86
SynHhld2	3708	2094	711	275	91	6879	1.27
SynHhld3	3650	2108	730	305	86	6879	6.19
SynHhld4	3692	2118	725	263	81	6879	1.71
SynHhld5	3697	2082	723	286	91	6879	1.79
SynHhld6	3711	2111	694	289	74	6879	7.99
SynHhld7	3665	2142	716	268	88	6879	1.66
SynHhld8	3686	2096	721	295	81	6879	4.57
SynHhld9	3683	2085	734	300	77	6879	6.64
SynHhld10	3684	2104	737	265	89	6879	0.12

Five per cent critical value of χ^2 with four degrees of freedom is 9.49

Table 6 Results of goodness of fit test by number of cars in the population by adult couple family with and without children

	Number of Cars							
	0	1	2	3	4+	Not state	Total	Chi-square χ^2 (5 dof)
Adult Couple Family with Children								
Observed	406	4350	8529	2762	984	400	17431	
SynHhld1	391	4370	8496	2760	1012	402	17431	1.58
SynHhld2	405	4266	8619	2729	1015	397	17431	3.97
SynHhld3	381	4377	8522	2718	1041	392	17431	5.88
SynHhld4	375	4205	8659	2782	1002	408	17431	9.82
SynHhld5	380	4304	8618	2707	1025	397	17431	5.91
SynHhld6	436	4253	8592	2708	1047	395	17431	10.00
SynHhld7	363	4333	8523	2790	1033	389	17431	7.65
SynHhld8	409	4289	8529	2743	1063	398	17431	7.36
SynHhld9	385	4363	8631	2670	990	392	17431	5.61
SynHhld10	370	4341	8571	2748	1019	382	17431	5.54
Adult Couple Family without Children								
Observed	1236	7928	5038	534	78	424	15238	
SynHhld1	1240	7962	5023	509	83	421	15238	1.72
SynHhld2	1212	7948	5062	520	70	426	15238	1.83
SynHhld3	1240	7924	5076	520	77	401	15238	1.93
SynHhld4	1219	8043	4931	517	91	437	15238	7.28
SynHhld5	1232	7960	5058	513	63	412	15238	4.27
SynHhld6	1217	8077	4939	522	60	423	15238	9.46
SynHhld7	1219	8013	4996	499	74	437	15238	4.39
SynHhld8	1221	8017	5019	501	87	393	15238	6.60
SynHhld9	1190	8050	5040	479	79	400	15238	10.63
SynHhld10	1250	7946	5077	498	70	397	15238	5.47

Five per cent critical value of χ^2 with five degrees of freedom is 11.07

Table 7 Results of goodness of fit test by number of cars in the population by adult single parent family with children

	Number of Cars							
	0	1	2	3	4+	Not state	Total	Chi-square χ^2 (5 dof)
Observed	1354	3518	1369	312	64	262	6879	
SynHhld1	1329	3538	1359	311	58	284	6879	3.06
SynHhld2	1361	3506	1374	311	69	258	6879	0.55
SynHhld3	1349	3516	1360	320	68	266	6879	0.60
SynHhld4	1284	3528	1367	340	58	302	6879	12.83*
SynHhld5	1297	3520	1409	316	65	272	6879	4.02
SynHhld6	1338	3530	1370	309	44	288	6879	9.09
SynHhld7	1339	3530	1384	307	51	268	6879	3.23
SynHhld8	1352	3486	1391	317	59	274	6879	1.67
SynHhld9	1346	3430	1428	329	66	280	6879	7.02
SynHhld10	1366	3485	1390	310	66	262	6879	0.81

Five per cent critical value of χ^2 with five degrees of freedom is 11.07

The use of the synthetic household result into the microsimulation model

In the microsimulation model, each synthetic household is seen as an independent real population for a study area. It is one of the main input data, together with the travel survey data and network data, for the sub-model, Activity Travel Simulator. According to the household type, a 24-hour activity pattern will be simulated for all persons in each household by the simulator for a typical weekday day. The activity pattern includes each trip's start time, finish time, trip purpose and mode used for the trip, trip chain is also simulated at the same time. A more detailed introduction to the Activity Travel Simulator is given in Xu, Taylor and Hamnett (2003).

Conclusion

This paper has presented an approach for the generation of synthetic households to represent an entire population of travellers to a study area for microsimulation of travel demand forecast and travel behaviour analysis. The method includes two procedures. Firstly, it uses census data for reproducing the existing population at the census collector district level by applying Monte Carlo simulation. Secondly, it incorporates the most powerful spatial data management and analysis system, GIS into the operation system, the synthetic households thus can be assigned to available dwellings from detailed land use data to match the known socio-demographic characteristics of the study area population. The dwelling locations can be displayed either within the system or through popular GIS softwares, such as ArcView or ArcGIS to provide users with a visual explanation and interpretation of the dwelling assignment results. The advantage of using GIS technique within this method is that this will give the user help in the understanding of travel behaviour in some certain aspects. For example, the user can examine household travel behaviour within a certain distance from the bus station by selecting these households from the table. Therefore, travel behaviour and travel patterns of people living in any location can be analysed through the microsimulation model if the synthetic populations are input as representatives of the observed population.

The operation system was developed in an OOP environment, which provides the user to carry out the procedures with an easy manner. The paper has showed validation results from the generation of synthetic households for adult couple families for a study area. The validation results indicate that this procedure has performed very well as synthetic populations generated by this method have similar characteristics to the observed population.

Acknowledgement

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