WORKING PAPER 533

INCORPORATING MIGRATION INTO SIMULATION MODELS

Chris Duley

GMAP Ltd

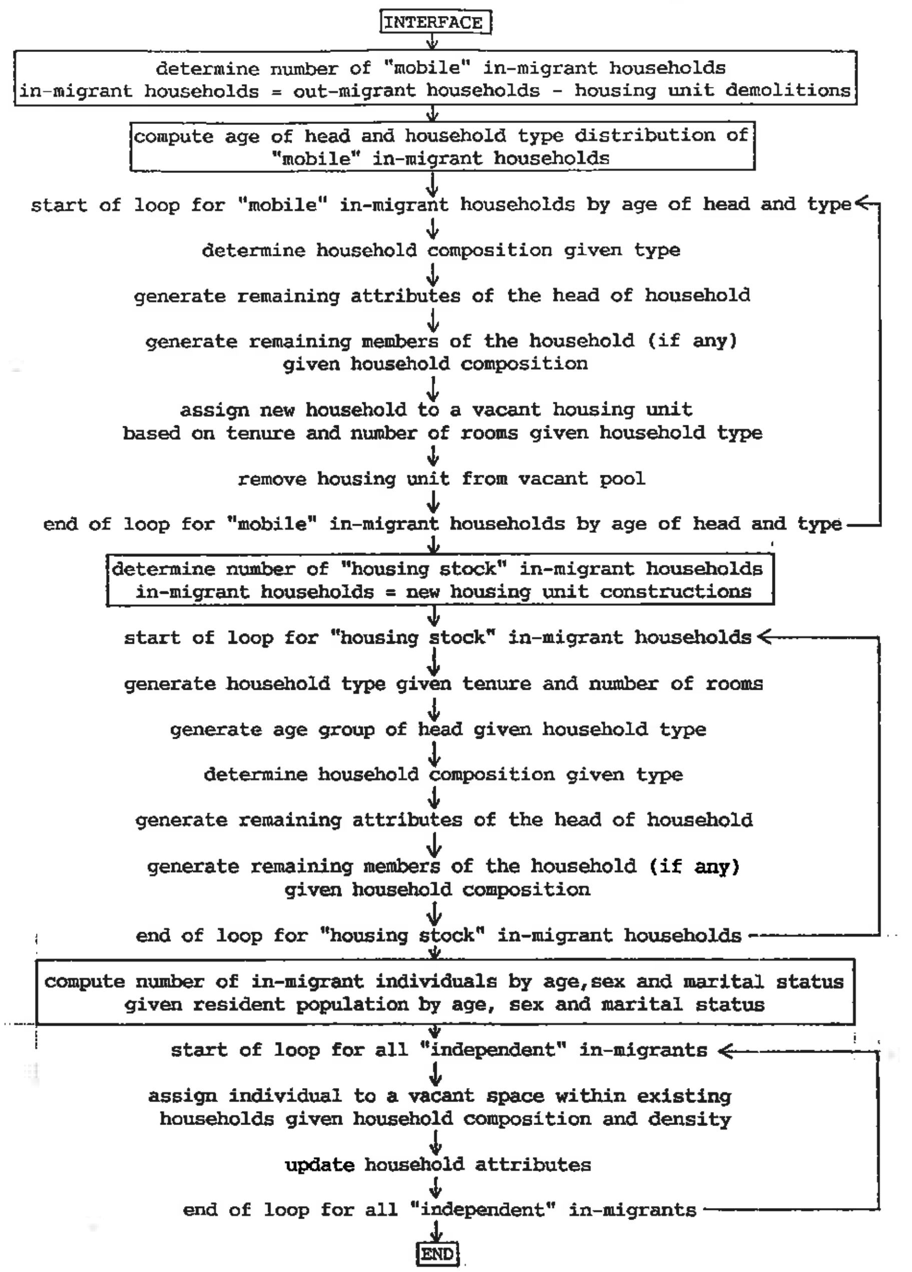
and

Phil Rees

School of Geography

University of Leeds
Leeds LS2 9JT

FIGURE 5. Stages in the simulation of in-migration of households and individuals



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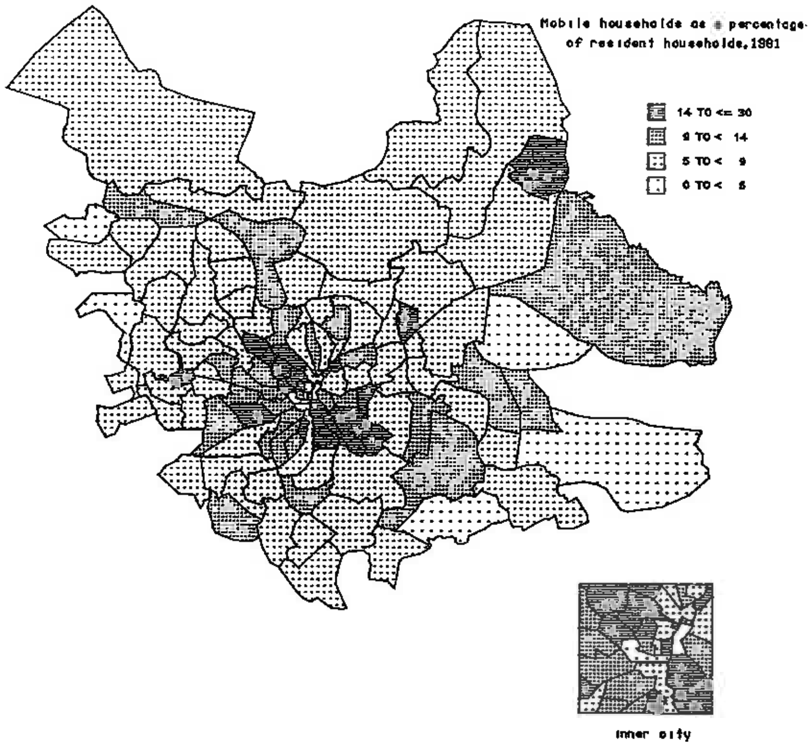
Chapter 12 in MODELLING INTERNAL MIGRATION edited by John Stillwell (University of Leeds) and Peter Congdon (London Research Centre), to be published by Belhaven Press, London.

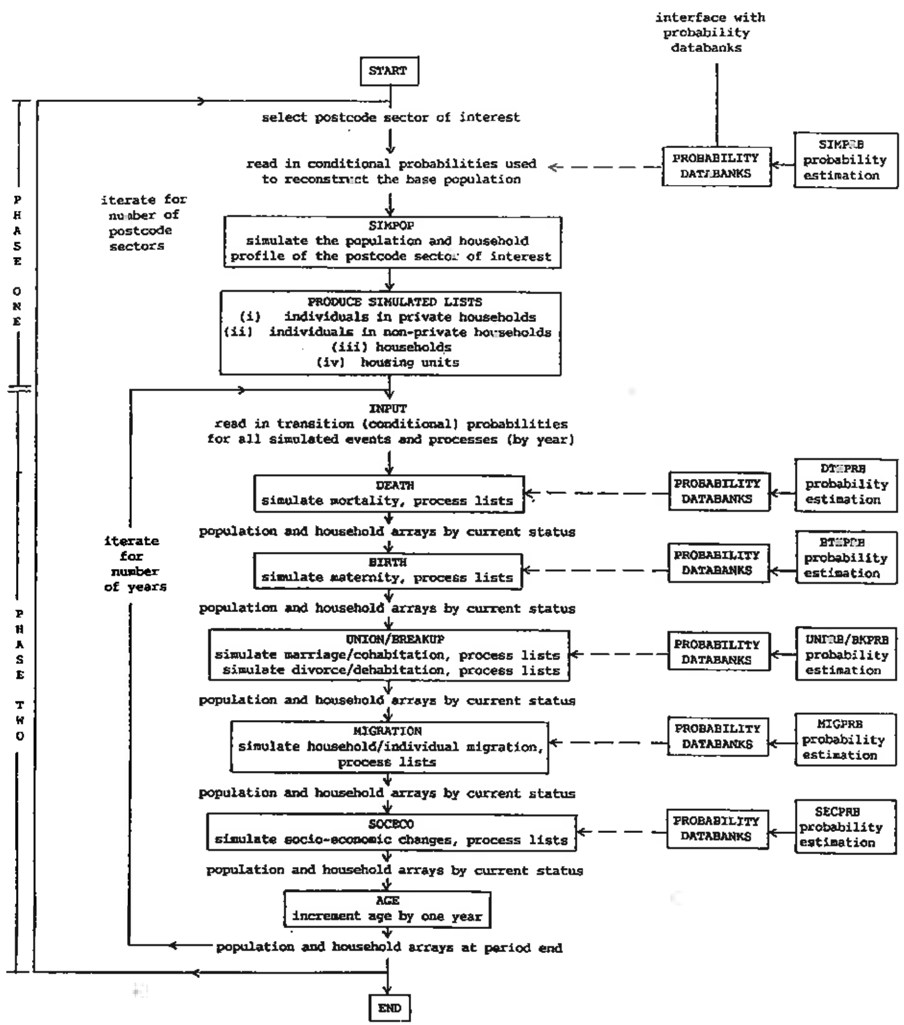
Paper presented at the Twenty First Annual Conference of the Regional Science Association, British Section, 5-7 September 1990, University of Liverpool.

FIGURE 3. Household mobility rates by postcode sector, Leeds 1981



CONTENTS

FIGURE 1. The structure of the UPDATE simulation system



"Had we but world enough, and time,
This coyness lady were no crime ...
But at my back I always hear
Time's winged chariot hurrying near."
(Andrew Marvell, To his coy mistress, 1650).

1. THE UPDATING PROBLEM AND SOLUTIONS

1.1 The updating problem

We wait ten years between censuses for new information about the socioeconomic geography of our country. Writing in 1990, the last firm and reliable picture of the poulation size and charcter of our regions, counties, cities and neighbourhoods derives from the 1981 Census of Population.

There are a number of partial sources of information which are tapped by geographers, local government analysts and market analysis firms to update the populations of districts and wards in the United Kingdom. These include the following.

(1) Surveys are carried out each year or every other year, such as the General Household Survey, the Labour Force Survey and the Family Expenditure Survey, which make enquiries of national samples of households.

(2) Partial registers can be used, such as the Electoral Register which counts all those eligible to vote and willing to register or the National Health Service Central Register (NHSCR), from which counts are made of persons transferring between Family Practitioner Committee (FPC) areas (soon to be called Family Health Services Authorities).

(3) Vital statistics registers yield useful information on new additions and subtractions from the population. The Office of Population Censuses and Surveys (OPCS) regularly publishes annual counts of births and deaths (with some age disaggregation) for areas down to ward and parish level.

(4) Information on the number of new housing units completed each year in each local government unit is reported to the Department of the Environment to make up national tabulations.

There is a clear need to develop methods which utilize both the more detailed but less timely Census data for small areas and the

TABLE 8. Destination selection: the division of movement within and without the small area, postal sectors in Leeds

sector	within	without	sector	within	without	sector	within	without
LS1 2	0.003	0.997	LS1 3	0.001	0.999	LS1 4	0.001	0.999
LS1 5	0.000	0.000	LS1 6	0.001	0.999	LS10 1	0.103	0.897
LS10 2	0.250	0.750	LS10 3	0.185	0.815	LS10 4	0.283	0.717
LS11 0	0.050	0.950	LS11 5	0.042	0.958	LS11 6	0.088	0.912
LS11 7	0.103	0.897	LS11 8	0.079	0.921	LS11 9	0.024	0.976
LS12 1	0.042	0.958	LS12 2	0.046	0.954	LS12 3	0.068	0.932
LS12 4	0.091	0.909	LS12 5	0.076	0.924	LS12 6	0.013	0.987
LS13 1	0.063	0.937	LS13 2	0.134	0.866	LS13 3	0.112	0.888
LS13 4	0.093	0.907	LS14 1	0.052	0.948	LS14 2	0.084	0.916
LS14 3	0.048	0.952	LS14 5	0.083	0.917	LS14 6	0.094	0.906
LS15 0	0.097	0.903	LS15 4	0.056	0.944	LS15 7	0.076	0.924
LS15 8	0.090	0.910	LS15 9	0.012	0.988	LS16 5	0.031	0.969
LS16 6	0.069	0.931	LS16 7	0.095	0.905	LS16 8	0.032	0.968
LS16 9	0.146	0.854	LS17 5	0.046	0.954	LS17 6	0.051	0.949
LS17 7	0.123	0.877	LS17 8	0.092	0.908	LS17 9	0.077	0.923
LS18 4	0.071	0.929	LS18 5	0.092	0.908	LS19 6	0.115	0.885
LS19 7	0.266	0.734	LS2 8	0.003	0.997	LS2 9	0.019	0.981
LS20 8	0.325	0.675	LS20 9	0.163	0.837	LS21 1	0.277	0.723
LS21 2	0.424	0.576	LS21 3	0.314	0.686	LS22 4	0.715	0.285
LS22 5	0.152	0.848	LS23 6	0.546	0.454	LS23 7	0.398	0.602
LS24 9	0.111	0.889	LS25 1	0.128	0.872	LS25 2	0.145	0.855
LS25 3	0.037	0.963	LS25 4	0.132	0.868	LS25 5	0.011	0.989
LS25 7	0.337	0.663	LS26 0	0.220	0.780	LS26 8	0.292	0.708
LS26 9	0.075	0.925	LS27 0	0.225	0.775	LS27 7	0.077	0.923
LS27 8	0.108	0.892	LS27 9	0.109	0.891	LS28 5	0.164	0.836
LS28 6	0.129	0.871	LS28 7	0.122	0.878	LS28 8	0.116	0.884
LS28 9	0.058	0.942	LS29 6	0.014	0.986	LS3 1	0.018	0.982
LS4 2	0.047	0.952	LS5 3	0.043	0.957	LS6 1	0.135	0.865
LS6 2	0.050	0.950	LS6 3	0.076	0.924	LS6 4	0.049	0.951
LS7 1	0.017	0.983	LS7 2	0.040	0.960	LS7 3	0.067	0.933
LS8 1	0.051	0.949	LS8 2	0.048	0.952	LS8 3	0.057	0.943
LS8 4	0.087	0.913	LS8 5	0.058	0.942	LS9 0	0.115	0.885
LS9 6	0.073	0.927	LS9 7	0.083	0.917	LS9 8	0.068	0.932
LS9 9	0.035	0.965	LS7 4	0.042	0.958	BD10 0	0.000	0.000
BD11 1	0.110	0.890	BD3 7	0.029	0.971	BD4 8	0.073	0.927
WF10 2	0.202	0.798	WF2 0	0.034	0.966	WF3 1	0.144	0.856
WF3 2	0.127	0.873	WF3 3	0.167	0.833	WF3 4	0.054	0.946

methodology.

1.3 A microsimulation method

Duley (1989), building on Rees, Clarke and Duley (1987), Duley, Rees and Clarke (1988) and Clarke, Duley and Rees (1989), has constructed an alternative method which produces post-censal estimates of the population, broken down not only by age and gender but by household position, living arrangement, marital status and ethnic group and which produces estimates of the number and character of households as well. The method involves microsimulation.

Briefly, lists of households and the constituent individuals in the population of a small area are produced by random sampling of cumulative probability distributions of characteristics. The probability distributions are computed from small area, regional and national census data and other sources. Wherever possible interdependencies between characteristics are incorporated. The result of the first, reconstruction, phase of the model is a partial reproduction of the census at household and individual level. Then, in the second, updating, phase, both individuals and households are subjected to a series of demographic and social processes: mortality, fertility, union/breakup, migration and socioeconomic change. In the third, projection, phase, households and individuals continue to experience these processes but the probability distributions used are forecast rather than estimated using contemporary information. The methods in this third phase are the same as those in the second; it is just the nature of the input information that is different.

TABLE 6. The probability of an "independent" person migrating from a small area, 1981-86, the example of Leeds postal sector LS6 1

		male			female		
	age	married	single	wid/div	married	single	wid/div
	16-20	0.0136	0.0071	0.0069	0.0328	0.0082	0.0278
	21-24	0.0096	0.0136	0.0298	0.0190	0.0159	0.0320
1	25-29	0.0049	0.0144	0.0281	0.0098	0.0145	0.0204
	30-34	0.0030	0.0073	0.0148	0.0049	0.0032	0.0045
9	35-39	0.0020	0.0046	0.0119	0.0034	0.0021	0.0035
	40-44	0.0015	0.0045	0.0089	0.0025	0.0018	0.0026
8	45-49	0.0001	0.0020	0.0044	0.0030	0.0019	0.0030
	50-54	0.0001	0.0017	0.0033	0.0027	0.0017	0.0029
1	55-59	0.0001	0.0018	0.0020	0.0026	0.0018	0.0025
	60-64	0.0001	0.0016	0.0019	0.0025	0.0014	0.0022
	65-69	0.0015	0.0019	0.0021	0.0012	0.0011	0.0017
	70-74	0.0014	0.0022	0.0021	0.0010	0.0011	0.0017
	75+	0.0013	0.0019	0.0026	0.0011	0.0017	0.0021
	16-20	0.0157	0.0081	0.0080	0.0342	0.0086	0.0290
	21-24	0.0092	0.0131	0.0285	0.0174	0.0145	0.0293
1	25-29	0.0039	0.0116	0.0226	0.0090	0.0133	0.0188
	30-34	0.0025	0.0061	0.0123	0.0044	0.0029	0.0041
9	35-39	0.0020	0.0046	0.0119	0.0027	0.0017	0.0028
	40-44	0.0019	0.0055	0.0109	0.0030	0.0022	0.0031
8	45-49	0.0001	0.0021	0.0047	0.0022	0.0014	0.0023
	50-54	0.0001	0.0014	0.0027	0.0024	0.0015	0.0026
2	55-59	0.0001	0.0026	0.0028	0.0034	0.0023	0.0032
	60-64	0.0001	0.0018	0.0021	0.0034	0.0020	0.0031
	65-69	0.0010	0.0013	0.0015	0.0006	0.0005	0.0007
	70-74	0.0010	0.0016	0.0015	0.0008	0.0009	0.0014
	75+	0.0012	0.0017	0.0022	0.0013	0.0021	0.0026
	16-20	0.0142	0.0074	0.0072	0.0319	0.0080	0.0270
	21-24	0.0089	0.0126	0.0275	0.0167	0.0139	0.0281
1	25-29	0.0038	0.0111	0.0217	0.0091	0.0135	0.0191
	30-34	0.0022	0.0054	0.0109	0.0044	0.0029	0.0041
9	35-39	0.0024	0.0054	0.0142	0.0027	0.0017	0.0028
	40-44	0.0014	0.0043	0.0084	0.0030	0.0022	0.0031
8	45-49	0.0001	0.0018	0.0040	0.0028	0.0017	0.0028
	50-54	0.0001	0.0016	0.0030	0.0023	0.0015	0.0025
3	55-59	0.0001	0.0026	0.0028	0.0023	0.0016	0.0022
	60-64	0.0000	0.0008	0.0009	0.0031	0.0018	0.0027
	65-69	0.0010	0.0013	0.0015	0.0010	0.0009	0.0014
	70-74	0.0010	0.0016	0.0015	0.0009	0.0010	0.0015
	75+	0.0013	0.0019	0.0026	0.0016	0.0025	0.0030

		male			female		
	age	married	single	wid/div	married	single	wid/div
	16-20	0.0119	0.0062	0.0061	0.0265	0.0066	0.0225
	21-24	0.0098	0.0139	0.0304	0.0178	0.0149	0.0300
1	25-29	0.0049	0.0144	0.0282	0.0101	0.0150	0.0212
	30-34	0.0027	0.0067	0.0135	0.0047	0.0031	0.0043
9	35-39	0.0025	0.0059	0.0154	0.0048	0.0030	0.0050
	40-44	0.0017	0.0051	0.0101	0.0036	0.0026	0.0037
8	45-49	0.0001	0.0019	0.0041	0.0028	0.0017	0.0028
	50-54	0.0001	0.0021	0.0040	0.0027	0.0017	0.0029
4	55-59	0.0001	0.0025	0.0028	0.0032	0.0021	0.0030
	60-64	0.0001	0.0018	0.0020	0.0032	0.0018	0.0028
	65-69	0.0019	0.0024	0.0027	0.0013	0.0011	0.0017
	70-74	0.0019	0.0029	0.0028	0.0010	0.0011	0.0017
	75+	0.0014	0.0021	0.0028	0.0019	0.0030	0.0036
	16-20	0.0130	0.0067	0.0066	0.0271	0.0068	0.0230
	21-24	0.0098	0.0140	0.0306	0.0190	0.0159	0.0320
1	25-29	0.0049	0.0144	0.0281	0.0103	0.0153	0.0215
	30-34	0.0027	0.0067	0.0136	0.0053	0.0035	0.0049
9	35-39	0.0027	0.0062	0.0163	0.0044	0.0027	0.0046
	40-44	0.0019	0.0058	0.0114	0.0037	0.0027	0.0038
8	45-49	0.0002	0.0022	0.0049	0.0035	0.0021	0.0035
	50-54	0.0001	0.0020	0.0038	0.0026	0.0016	0.0027
5	55-59	0.0001	0.0027	0.0030	0.0030	0.0021	0.002[illegible]
	60-64	0.0001	0.0019	0.0022	0.0033	0.0019	0.0029
	65-69	0.0014	0.0017	0.0020	0.0013	0.0011	0.0017
	70-74	0.0017	0.0026	0.0025	0.0009	0.0009	0.0015
	75+	0.0014	0.0020	0.0028	0.0019	0.0031	0.0037
	16-20	0.0117	0.0060	0.0059	0.0244	0.0061	0.0206
	21-24	0.0096	0.0136	0.0298	0.0194	0.0162	0.0326
1	25-29	0.0051	0.0151	0.0296	0.0113	0.0168	0.0237
	30-34	0.0027	0.0066	0.0132	0.0050	0.0033	0.0046
9	35-39	0.0025	0.0058	0.0152	0.0045	0.0028	0.0047
	40-44	0.0020	0.0059	0.0117	0.0037	0.0026	0.0037
8	45-49	0.0002	0.0025	0.0055	0.0030	0.0018	0.0030
	50-54	0.0001	0.0019	0.0037	0.0025	0.0016	0.0027
6	55-59	0.0001	0.0027	0.0029	0.0033	0.0023	0.0031
	60-64	0.0001	0.0016	0.0019	0.0028	0.0016	0.0025
	65-69	0.0012	0.0015	0.0017	0.0014	0.0013	0.0019
	70-74	0.0016	0.0025	0.0024	0.0007	0.0007	0.0012
	75+	0.0016	0.0023	0.0031	0.0019	0.0030	0.0036

source: computed in UPDATE

1.5 The migration framework used in the UPDATE model

To incorporate migration into the UPDATE microsimulation model involved eclectic use of a variety of data sources, of a variety of observations and associated models long recognized in descriptive research and of some new concepts.

(1) Migration associated with pair formation and dissolution
It is recognized that the process of formal or informal formation of couples through marriage or cohabitation will lead to migration by at least one of the couple. Similarly, divorce or dehabitation will also lead to migration of at least one member of the fissioning couple. Full details of how the migration consequences are worked out are given in the second section of the paper.

(2) The migration of whole households and of independent individuals within and out of an area
The migration submodel (which follows the union/breakup submodel) is designed to simulate both the migration of whole households and that of individuals who leave a household. It is important to recognize these two different types of migration. An individual can move from one existing household to another existing household. An example might be the migration of an 18 year old from the parental home to a room in a hall of residence (i.e. a space in a non-private household).

Out-migration by households and individuals from an area is generated by the sampling of probabilities of migrating (anywhere) and the probability that the migration destination will fall within the area or outside it. This second probability of relocation inside or outside an area is sensitive to the size of the area used and the distribution of opportunities elsewhere. The data employed to estimate the probabilities are the inter- and intra-ward migration observed in the year prior to the 1981 Census. To link these data with a set of postcode zones a spatial interaction model is used.

(3) In-migration to an area
In-migration of households to an area occurs in response to vacancies created through out-migration of households or as a result of the construction of new housing. Some of the vacancies are taken up by households moving within the area, and some by households moving from outside. characteristics of these new households and their individual members must be reconstructed through application of the same methods used to reconstruct the starting population.

In the body of the paper flesh is added to this skeletal outline of the ways migration processes can be incorporated into simulation models of small area populations. The second section of

TABLE 4. Housing unit accounts for postcode sectors, Leeds, 1981-86

sector label	1981 housing stock	4/1981-9/1986 housing unit +	-	net
LS1 2	49	2	1	1
LS1 3	46	3	4	-1
LS1 4	157	9	12	-3
LS1 5	0	0	0	0
LS1 6	27	1	0	1
LS10 1	1060	95	169	-74
LS10 2	2263	236	415	-179
LS10 3	5166	464	681	-217
LS10 4	4424	227	2	225
LS11 0	1996	51	10	41
LS11 5	2651	74	17	57
LS11 6	2315	81	25	56
LS11 7	3626	80	11	69
LS11 8	3223	101	27	74
LS11 9	1443	59	21	38
LS12 1	1984	65	68	-3
LS12 2	2482	61	135	-74
LS12 3	3362	91	123	-32
LS12 4	3325	110	7	103
LS12 5	3588	115	2	113
LS12 6	872	29	2	27
LS13 1	2480	89	17	72
LS13 2	4777	212	137	75
LS13 3	3671	198	60	138
LS13 4	4249	88	81	7
LS14 1	3427	58	0	58
LS14 2	1451	105	0	105
LS14 3	966	51	0	51
LS14 5	3627	262	0	262
LS14 6	5626	4	9	-5
LS15 0	3687	179	72	107
LS15 4	2043	118	0	118
LS15 7	3878	253	9	244
LS15 8	3724	402	0	402
LS15 9	337	37	0	37
LS16 5	2812	61	7	54
LS16 6	4007	258	1	257
LS16 7	4347	422	0	422
LS16 8	1267	120	0	120
LS16 9	1227	20	0	20
LS17 5	3848	196	0	196
LS17 6	3850	97	0	97
LS17 7	3688	279	0	279
LS17 8	3662	223	4	219
LS17 9	1210	94	0	94
LS18 4	3635	70	0	70
LS18 5	3540	69	0	69
LS19 6	2505	58	0	58
LS19 7	4999	182	0	182
LS2 8	320	18	25	-7
LS2 9	720	41	55	-14
LS20 8	2362	93	0	93
LS20 9	2008	79	0	79
LS21 1	2008	33	0	33
LS21 2	2330	38	0	38
LS21 3	2114	34	0	34

sector label	1981 housing stock	4/1981-9/1986 housing unit +	-	net
LS22 4	3481	271	0	271
LS22 5	879	68	0	68
LS23 6	2575	200	0	200
LS23 7	292	23	0	23
LS24 9	136	11	0	11
LS25 1	3094	102	28	74
LS25 2	2663	88	24	64
LS25 3	521	24	0	24
LS25 4	700	32	0	32
LS25 5	67	3	0	3
LS25 7	3550	162	0	162
LS26 0	4895	54	0	54
LS26 8	4435	87	17	70
LS26 9	1416	42	11	31
LS27 0	2693	149	9	140
LS27 7	3283	107	2	105
LS27 8	3050	176	11	165
LS27 9	2435	91	3	88
LS28 5	4297	81	0	81
LS28 6	1748	61	11	50
LS28 7	3656	55	0	55
LS28 8	2986	39	0	39
LS28 9	2084	23	0	23
LS29 6	149	6	0	6
LS3 1	948	55	73	-18
LS4 2	3848	192	45	147
LS5 3	3193	153	48	105
LS6 1	5285	142	130	12
LS6 2	2977	123	152	-29
LS6 3	4257	120	71	49
LS6 4	3534	57	1	56
LS7 1	1382	80	106	-26
LS7 2	3432	110	45	65
LS7 3	4074	152	21	131
LS7 4	2842	109	24	85
LS8 1	3754	94	8	86
LS8 2	4599	126	15	111
LS8 3	4506	46	2	44
LS8 4	2409	56	6	50
LS8 5	3885	110	111	-1
LS9 0	3288	34	100	-66
LS9 6	5489	17	47	-30
LS9 7	4100	106	144	-38
LS9 8	1703	17	44	-27
LS9 9	2257	24	71	-47
BD10 0	0	0	0	0
BD11 1	1780	54	1	53
BD3 7	340	6	0	6
BD4 8	630	7	0	7
WF10 2	1679	77	0	77
WF2 0	192	13	1	12
WF3 1	2643	178	12	166
WF3 2	1567	106	7	99
WF3 3	2125	92	0	92
WF3 4	207	2	0	2
all pcs	282471	10907	3608	7299

2.1 The marriage and cohabitation model

The model adopted to handle pair formation at the micro-level is an extension of the developed by Clarke (1986), and adopts an open market, whereby migration is directly incorporated: individuals are free to migrate to find their spouse or cohabitee, with the result that individuals are added to or deleted from the population depending on the direction of the flow. The algorithm for marriage and cohabitation and its consequent events is set out in Figure 2. There were three stages: (1) testing each individual in the population for eligibility, with different criteria enabling different nuptial paths to be tracked; (2) testing the eligible individuals for marriage or cohabitation, with different events tested to cater for the different eligibility groups; and (3) matching selected individuals with partners and working out the consequent location decisions for both partners. Having divided prospective partners by sex, this step models the search for suitable partners in the local marriage and cohabitation market. The matching algorithm is based on the age combination of the potential partners at union.

Based on five year age group of a base partner, whose gender is selected at random, an imaginary partner (spouse or cohabitee) is generated with a given age. Then a match of this imaginary person with a locally available person from the relevant partner pool is attempted. If a local partner fitting the age-sex requirement is found a match is made and the two individuals are united and removed from their respective partner pools. If there is no suitable partner locally available then an interface with the wider marriage/cohabitation market outside the small area is necessary.

TABLE 2. The estimation of household numbers by age group of head and household type for Leeds district

(a) national data: households by age of head and type [1]

household type	16-29	30-44	45-64	65+	all ages
1	0.0000	0.0000	0.0000	0.1416	0.1416
2	0.0167	0.0203	0.0387	0.0000	0.0757
3	0.0075	0.0109	0.0024	0.0003	0.0211
4	0.0275	0.0277	0.0944	0.0954	0.2450
5	0.0572	0.1278	0.0241	0.0007	0.2098
6	0.0013	0.0110	0.0856	0.0192	0.1171
7	0.0030	0.0341	0.0413	0.0025	0.0809
8	0.0129	0.0130	0.0257	0.0343	0.0859
9	0.0045	0.0111	0.0062	0.0012	0.0230
all types	0.1306	0.2559	0.3183	0.2952	1.0000

(b) district marginal 1: households by type [2]
(c) district marginal 2: households by age of head [3]

household type	16-29	30-44	45-64	65+	all ages	probability
1					41288	0.1571
2					22791	0.0867
3					6436	0.0245
4					63941	0.2433
5					51463	0.1958
6					28265	0.1075
7					19758	0.0752
8					22143	0.0843
9					6721	0.0256
all types	33531	67048	95069	67158	262806	1.0000
probability	0.1276	0.2551	0.3618	0.2555	1.0000	-

(d) district estimate; households by age of head and type

household type	16-29	30-44	45-64	65+	all ages	probability
1	0	0	0	41288	41288	0.1571
2	4532	5874	12384	0	22790	0.0867
3	2182	3384	822	48	6436	0.0245
4	7735	8333	31302	16571	63941	0.2433
5	13230	31560	6566	106	51462	0.1958
6	281	2634	22682	2668	28265	0.1075
7	663	8026	10733	336	19758	0.0752
8	3649	3943	8566	5985	22143	0.0843
9	1247	3267	1997	210	6721	0.0256
all types	33519	67021	95052	67212	262804	1.0000
probability	0.1275	0.2550	0.3617	0.2558	1.0000	-

Source: 1 adjusted OPCS, 1983b, Table 26 (HH)
2 OPCS, 1983a, Table 39 (CR 45).
3 OPCS, 1983a, Table 35 (CR 45)

housing stocks are then searched and if a suitable dwelling is found the new couple is assigned to it. If no suitable vacant housing unit is available, in stage two, movement is restricted to one of the two partners so that the couple or family is formed in an existing household, with no new household being established.

2.2 The divorce and dehabitation model

The modelling of pair dissolution is more straightforward than that of marriage, in that no matching algorithm is required since it is this match that is split through the divorce or dehabitation process. However, the implications of pair dissolution are equally complex. Breakup is sampled on the basis of age, sex and ethnic group of the base partner, with sex having been first set at random to avoid gender bias. Certain assumptions concerning the outcome of the divorce/dehabitation transition were made. The first was that the male former partner invariably departs from the existing household and having left is deemed to set up a new single person household. Given the small area approach, the location of this new household is dependent on the availablity of suitable vacant housing (cf.marriage and cohabitation model), with out-migration following an unsuccessful search. The second assumption is that the female former partner and any child(ren) remain in their present dwelling unit with updated attributes reflecting their new circumstances. Both former partners become eligible for remarriage.

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(3) Temporal adjustment factor. This adjusted mobility probability is further adjusted up or down to reflect changes in mobility between 1980-81 and the current year of interest.

(4) Mobility probability due to demolition. To this adjusted mobility probability is added an additional mobility probability reflecting moves forced on households as a result of housing demolitions in the particular postcode sector of interest.

In other words,

$$ph^{ta}_{s}(y) = \text{initial district estimate} \times \text{spatial adjustment factor} \times \text{temporal adjustment factor} + \text{mobility probability due to demolition} \qquad (1)$$

How estimates of each of these elements are achieved is now described.

3.1 The initial district estimate. The target variable to be estimated is

$ph^{ta}_{d}(81)$ = the probability that a household of type t with a head in age group a living in district d migrates in the year prior to the 1981 Census

which may be approximated as

$$ph^{ta}_{d}(81) = MH^{ta}_{d}(81) \,/\, H^{ta}_{d}(81) \qquad (2)$$

where

$MH^{ta}_{d}(81)$ = households of type t and head's age a in district d who move in the census year 1980-81

$H^{ta}_{d}(81)$ = all households of type t and head's age a in district d

Neither of these variables is directly available from published sources, but single classifications of households by type and by head's age are available at the district level from Migration Regional Reports and the MATPAC system for migrant households, and from County Reports for all households. A national table cross-classifying households by type and head's age is also

5.4 Conclusions

There is a strong tradition of using microsimulation models to study the changing geography of population (Hagerstrand 1957; Morrill 1965; Woods 1981). The focus in previous work has been on migration occurring in a fine network of areas to a simply classified population of individuals. The focus in this work has been on tracing the migration behaviour of a richly classified set of households and associated individuals in a rather simple set of areas. In so doing migration has been regarded as the outcome of several important processes which interface intimately with both the marriage and housing markets, In common with the earlier geographic tradition, we have had to think imaginatively of ways in which the probabilities and numbers required in the microsimulation process can be estimated. The estimation procedures have been presented in some detail. The results of the estimation have considerable interest in themselves, but in the case of the present work are seen only as means to a more ambitious end, that of updating the population of small areas within cities or counties between Censuses, retaining a good proportion of the richness of character available in those decennial, national endeavours.

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family households, those with lone parents are most mobile (type 3). Of married couple family households (types 4, 5, 6 and 7) those with no children under 16 are most migratory, with mobility declining with increased household size. Of the remaining types (types 8 and 9) multi-adult, non- or lone parent-family households, mobility corresponds more to that of married couples, suggesting the stabilising effect of larger household size.

3.1.2 The spatial adjustment factor. The district estimates need adjustment when used for individual postcode sectors. Mobility rates for households and for the whole population can be computed from data in the Small Area Statistics of the 1981 Census

$$mh_s(81) = \Sigma_e \, (MH_e(81) \, / \, H_e(81)\,) \qquad (3)$$

where

$mh_s(81)$ = the mobility rate for postcode sector s in 1980-81

$MH_e(81)$ = the number of wholly moving households (i.e. with a different address at the 1981 Census than one year earlier) in enumeration district e

$H_e(81)$ = the total number of households in enumeration district e.

The summation in equation (3) is over all enumeration districts which have been assigned to a postal sector. Enumeration districts were allocated to postal sectors by centroid matching checked by map inspection. The adjustment factor applied to the district mobility probabilities is the ratio of the sector mobility rate to that for the district d,

$$\text{spatial adjustment factor for postal sector s} = mh_s(81) \, / \, mh_d(81) \qquad (4)$$

To obtain a better understanding of the geography of mobility in Leeds, Figure 3 maps out these mobility rates. The district wide figure is just over 9%, yet sector figures range from over 25%

housing units are generated and added to vacant housing stocks. Tenure is determined first from which number of rooms and amenity provision are assigned.

Thirdly, each household in the migrant pool is assigned a destination, sampling from the same local distance function applied to individuals. If deemed to leave the area, the household and its members are deleted from the local lists, with the running out-migrant household total being incremented by one. If deemed to stay within the area, the household is assigned to a vacant housing unit. "Imaginary" tenure and number of rooms are generated given the household type of the mobile household. Local vacant housing stocks are then searched to find a "real" housing unit with the required attributes, which is then matched with the homeless household, and removed from the vacant housing pool.

5.3 The simulation of the number of in-migrant households and individuals and their characteristics

Firstly, in-migrant households are simulated. Given the distinction of "mobile" and "stock" based in-migrant households this task is split into two. Adopting the assumption that there is not net migration effect on household numbers induced by the mobility component, "mobile" in-migrant numbers are computed from out-migrant numbers reduced in line with demolitions of existing housing units (stock push effect). The migrant character of these households is established next. The in-migrant households are distributed amongst the type and age of head groups using local estimates. Proceeding through each age-type combination, each household assigned to it is then fully reconstructed (cf. population reconstruction). First, household type is converted to a corresponding broad household composition category (summing

construction of a new housing estate or the demolition of a 1960s flat complex will have a sudden and major impact of movement into and out of small area. Data on housing unit dynamics are available quarterly at local government level (Local Housing Statistics, England and Wales produced by the Department of the Environment). Although this is a valuable total constraint, the UPDATE model requires housing unit constructions and demolitions at the more detailed spatial scale of the postal sector.

Table 4 presents estimated postal sector housing unit demolitions and constructions for the period April 1981 to September 1986, computed from Leeds City Planning Department ward figures. An annual figure can be estimated by the simple deconsolidation of the 6 year aggregate. Not only has there been a small but significant increase in Leeds housing stocks, but more importantly, there has been considerable local variation in stock changes, ranging from large scale demolitions to equally large-scale new housing constructions. Broadly, there has been a net reduction in stocks in inner urban areas and net expansion in suburban housing stocks.

The mobility probability due to housing demolitions can be estimated as

$$DU_s(y) \;/\; TU_s(y)$$

where $DU_s(y)$ = the number of housing units demolished in postcode sector s at the start of year y.

and $TU_s(y)$ = the total number of units in postcode sector s in year y

3.1.5 The model for estimating mobility probabilities for wholly moving households. We can now bring together the detailed defintions and estimates outlined in the four previous subsections housing units and in part by the collective demographic and socio-economic character of the small area. The detailed reconstruction of the in-migrant population is carried out using modified versions of the techniques used to reconstruct the starting stock of households and individuals in the small area. Full details are given in Duley (1990, section 7.2.8).

5. IMPLEMENTING MIGRATION IN THE MICROSIMULATION MODEL

How are the probability distributions described in the third section of the paper and the in-migrant numbers described in the fourth section handled in the microsimulation? Two figures show how the results of the estimation work are used. Figure 4 highlights stages in the modelling of the mobility and destination processes, while Figure 5 sets out the stages involved in adding in-migrants to the small area population.

5.1 The testing of existing households and eligible individuals for mobility

Each household in the small area is tested for migration as a whole, using the standard Monte Carlo sampling technique. Testing is carried out on the basis of the age of the head and the type of household comprising the "whole". If movement is deemed to occur, the household is placed in a pool of migrant households. The associated housing unit, previously occupied, is added to the vacant housing pool becoming eligible for reoccupation. The next household is then processed and so on. If the household is deemed to stay, and is not a single person household, eligible individuals within it are tested for independent migration on the basis of their age, sex and marital status. Such individuals are confined to non-family adults and non-dependent children. Members of formal

formal and informal couples, whose migration related to pair dissolution is modelled separately in the BREAKUP module.

Similar steps to those employed for wholly moving households are used to estimate individual mobility probabilities, with the exclusion of the housing stock component. The target variable to be estimated is as follows:

$pi^{agm}_{s}(y)$ = probability that an independent individual of age a, gender g, marital status m in postal sector s migrates in year y.

This probability is estimated as follows:

$pi^{agm}_{s}(y)$ = initial district estimate
x spatial adjustment factor
x temporal adjustment factor
x reduction factor to reflect prior migration in the pair formation and dissolution process (7).

3.2.1 The initial district estimate. An estimate of the probability of migration for independent individuals at district level involves the subtraction of non-eligible individuals from both the migrant count of individuals and from the population divisor. All household heads and their *de facto* spouses were deleted. Full details are given in Duley (1989, Chapter 7, section 7.2.5). The initial district estimate was adjusted downwards by the ratio of reported "independent" or "lone" migrants to the reduced number of migrants:

$$pi^{agm}_{d}(81) = (MiR^{agm}_{d}(81) / PiR^{agm}_{d}(81)) \times (\text{total lone migrants} / \Sigma_a \Sigma_g \Sigma_m MiR^{agm}_{d}(81)) \quad (8)$$

staying. Table 8 presents the within/without dichotomy for Leeds postal sectors. The variation is considerable, ranging from near negligible intra-area flows within LS 1 to large and in some cases dominant flows within peripheral postal sectors, those in LS21 and LS22, for example. Such a distribution can be explained broadly on the basis that migrants have further to travel to cross boundaries in the larger peripheral postal sectors. However, this relationship is constrained somewhat by local housing stock that increases the attractiveness of the destination sector, and intervening opportunities that reduce the distance of moves.

Within area movers are then matched to vacant dwellings in the housing pool of the small area. Their successful matching is based on a probabilistic matching of their respective attributes: housing provision versus housing requirement (size of household - size of unit; disposable household income - purchase price/rantal value). The mechnaisms for such matching, the links between housing units, households and /or individuals is provided by pointers or common reference numbers.

4. THE ESTIMATION AND RECONSTRUCTION OF IN-MIGRANT HOUSEHOLDS AND INDIVIDUALS

4.1 The estimation of in-migrant numbers

The units in the housing pool not taken up by moving hosueholds, and housing spaces within existing households not taken up by moving individuals resident at the start of the time inetrval are then available for occupation by new, in-migrating households and individuals.

Central to the modelling of migration at the small area scale is the role of the "pull" of vacant housing stock. Very simply,

3.2.4 The reduction factor to allow for prior migration in the pair formation and dissolution process. Account must be taken of "independent" individual migration already modelled in the pair formation and dissolution process. The number of such migrants is counted as the model runs and expressed as a ratio to the total number of persons migrating, and this is subtracted from unity:

$$\text{reduction factor} = [1 - (PM^{agm}_s(y)/TM^{agm}_s(y))] \qquad (9)$$

where $PM^{agm}_s(y)$ = the number of "pair" migrants of age a, gender g and marital status m simulated during pair formation and dissolution who move from postcode sector s in year y

$TM^{agm}_s(y)$ = total number of migrants of age a, gender g and marital status m expected to migrate in postcode sector s in year y.

3.2.5 The model for estimating mobility probabilities for independent individuals. The total number of migrants is estimated by multiplication of the probabilities defined in equation (9) by the local, small area population at risk. Using the reduction factor defined in equation (9) produces the final estimate of the mobility probabilities for "independent" individuals:

$$pi^{agm}_s(y) = pi^{agm}_d(81) \times (mi^{agm}_s(81) / mi^{agm}_d(81)) \times (o_r(y) / o_r(81)) \times [1 - (PM^{agm}_s(y) / TM^{agm}_s(y)] \qquad (10)$$

3.3 The probabilities of relocation within an area and of out-migration

3.3.1 The mobility pool. The first pass through the list of simulated households generates a pool of moving households and

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INCORPORATING MIGRATION INTO SIMULATION MODELS

Chris Duley

GMAP Ltd

and

Phil Rees

School of Geography

University of Leeds
Leeds LS2 9JT

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ABSTRACT

The paper describes how migration processes were incorporated in a microsimulation model of small area populations that can be used to update census statistics. A new conceptual framework for handling the migration of households and independent individuals is developed. The probabilities input to the microsimulation model involve eclectic use of a wide variety of data sources and familiar models of migration.

"Had we but world enough, and time,
This coyness lady were no crime ...
But at my back I always hear
Time's winged chariot hurrying near."
(Andrew Marvell, To his coy mistress, 1650).

1. THE UPDATING PROBLEM AND SOLUTIONS

1.1 The updating problem

We wait ten years between censuses for new information about the socioeconomic geography of our country. Writing in 1990, the last firm and reliable picture of the poulation size and charcter of our regions, counties, cities and neighbourhoods derives from the 1981 Census of Population.

There are a number of partial sources of information which are tapped by geographers, local government analysts and market analysis firms to update the populations of districts and wards in the United Kingdom. These include the following.

(1) Surveys are carried out each year or every other year, such as the General Household Survey, the Labour Force Survey and the Family Expenditure Survey, which make enquiries of national samples of households.

(2) Partial registers can be used, such as the Electoral Register which counts all those eligible to vote and willing to register or the National Health Service Central Register (NHSCR), from which counts are made of persons transferring between Family Practitioner Committee (FPC) areas (soon to be called Family Health Services Authorities).

(3) Vital statistics registers yield useful information on new additions and subtractions from the population. The Office of Population Censuses and Surveys (OPCS) regularly publishes annual counts of births and deaths (with some age disaggregation) for areas down to ward and parish level.

(4) Information on the number of new housing units completed each year in each local government unit is reported to the Department of the Environment to make up national tabulations.

There is a clear need to develop methods which utilize both the more detailed but less timely Census data for small areas and the less detailed but more timely survey and register data for larger areas to produce up-to-date estimates of the numbers of people living in small areas and their socioeconomic characteristics.

1.2 Existing methods

Several attempts have been made to accomplish this updating.

(1) OPCS produces each year estimates of the mid-year population of each local authority (county district, metropolitan district, London borough and health authority area) broken down by age and sex. The method involves simple cohort-component calculations:

> "This involves ageing-on the population to make it a year older, subtracting deaths classified by sex and age, adding in new births, and making allowances for migration" (Rowntree, 1990, p.33).

(2) The market analysis firm, CACI, has produced estimates at ward level using the census counts, annual births and deaths for wards and net migration estimates based on changes in electoral register counts from year to year.

(3) At the University of Leeds, several researchers (Rees et al 1990) have used iterative proportional fitting to produce estimates of ward populations based on census counts for wards, OPCS mid-year population estimates for districts and electoral register counts for wards.

These updating exercises have a number of drawbacks, if the analyst desires as full a picture of the socioeconomic character of the population as possible, and wishes to derive estimates for geographies other than electoral wards. The methods produce counts of persons by gender and five year age group (0-4 to 80-84 and 85 and over), but no more. OPCS provides estimates only down to county district scale. The CACI estimates and the University of Leeds' work are specific to electoral wards, though Rees et al (1990) successfully handle a mid-decade revision in ward boundaries. All the methods face difficulties in estimating the components of change at small geographical scales, and, in particular, in incorporating migration into the estimation methodology.

1.3 A microsimulation method

Duley (1989), building on Rees, Clarke and Duley (1987), Duley, Rees and Clarke (1988) and Clarke, Duley and Rees (1989), has constructed an alternative method which produces post-censal estimates of the population, broken down not only by age and gender but by household position, living arrangement, marital status and ethnic group and which produces estimates of the number and character of households as well. The method involves microsimulation.

Briefly, lists of households and the constituent individuals in the population of a small area are produced by random sampling of cumulative probability distributions of characteristics. The probability distributions are computed from small area, regional and national census data and other sources. Wherever possible interdependencies between characteristics are incorporated. The result of the first, reconstruction, phase of the model is a partial reproduction of the census at household and individual level. Then, in the second, updating, phase, both individuals and households are subjected to a series of demographic and social processes: mortality, fertility, union/breakup, migration and socioeconomic change. In the third, projection, phase, households and individuals continue to experience these processes but the probability distributions used are forecast rather than estimated using contemporary information. The methods in this third phase are the same as those in the second; it is just the nature of the input information that is different.

1.4 The structure of the UPDATE simulation system

Figure 1 sets out the general structure of the UPDATE model. The area level for which updated lists of households and individuals are produced is the postcode sector. The model processes the population of each postcode sector in turn. For convenience, the post code sectors corresponding to a local authority district are processed as a set. Information for a postcode sector (PCS) is normally derived by adding up or averaging the information for the Census enumeration districts (EDs) which it covers. The matching of EDs with a PCS can only be approximate for 1981 Census data. Where the relevant information is available only at ward level, it is assumed to apply to all constituent EDs from which a postcode aggregate or average can be obtained (see Duley 1989, sections 8.2.4 and 8.2.5 for details).

A key feature of population estimation and projection systems is the extent to which the spatial unit populations interact. In OPCS's subnational projections (Armitage 1986; Rees and Willekens 1989) and in the projections of the population of Swansea wards carried out by Rees et al 1990, migration is allowed between all areas in adapted forms of the multiregional population projection model (see Rees 1989 for a review of the current state of this model). However, in the UPDATE system each postcode sector is treated as a single, isolated system receiving in-migrants and sending out-migrants. The number of in-migrants is dependent on events within the postcode sector only, and not elsewhere as in the multiregional model. This simplification made it feasible to produce an operational model, and to incorporate a number of interesting innovations.

1.5 The migration framework used in the UPDATE model

To incorporate migration into the UPDATE microsimulation model involved eclectic use of a variety of data sources, of a variety of observations and associated models long recognized in descriptive research and of some new concepts.

(1) Migration associated with pair formation and dissolution
It is recognized that the process of formal or informal formation of couples through marriage or cohabitation will lead to migration by at least one of the couple. Similarly, divorce or dehabitation will also lead to migration of at least one member of the fissioning couple. Full details of how the migration consequences are worked out are given in the second section of the paper.

(2) The migration of whole households and of independent individuals within and out of an area
The migration submodel (which follows the union/breakup submodel) is designed to simulate both the migration of whole households and that of individuals who leave a household. It is important to recognize these two different types of migration. An individual can move from one existing household to another existing household. An example might be the migration of an 18 year old from the parental home to a room in a hall of residence (i.e. a space in a non-private household).

Out-migration by households and individuals from an area is generated by the sampling of probabilities of migrating (anywhere) and the probability that the migration destination will fall within the area or outside it. This second probability of relocation inside or outside an area is sensitive to the size of the area used and the distribution of opportunities elsewhere. The data employed to estimate the probabilities are the inter- and intra-ward migration observed in the year prior to the 1981 Census. To link these data with a set of postcode zones a spatial interaction model is used.

(3) In-migration to an area
In-migration of households to an area occurs in response to vacancies created through out-migration of households or as a result of the construction of new housing. Some of the vacancies are taken up by households moving within the area, and some by households moving from outside. characteristics of these new households and their individual members must be reconstructed through application of the same methods used to reconstruct the starting population.

In the body of the paper flesh is added to this skeletal outline of the ways migration processes can be incorporated into simulation models of small area populations. The second section of the paper deals with migration consequent on pair formation and pair dissolution. The third section of the paper considers the spatial and temporal features of the push migration models employed to estimate needed mobility and destination selection probabilities. The fourth section of the paper shows how a pull perspective can be used to model in-migrants to an area. The final section shows how the migration processes are implemented in the microsimulation model.

2. MIGRATION ASSOCIATED WITH PAIR FORMATION AND DISSOLUTION

The coupling and uncoupling of individuals has important implications for household dynamics. New households may be formed or existing households may be transformed or even dissolved. Frequently associated with these marital transitions is migration, either within the local area or to/from other areas.

In the UPDATE model two types of living arrangement were identified and modelled, the formal institution of marriage and the informal alternative, cohabitation. Registration requirements ensure that statistics on marriage and divorce are available (in Series FM2, published by OPCS). By contrast, the informal nature of cohabitation means that statistics on this increasingly popular contemporary living arrangement are sparse. No data are currently available on numbers of cohabitation events, formations or terminations, but estimates can be made from survey data on female cohabitation reported in the General Household Survey (GHS). From an amalgam of data sources probabilities are estimated for input to the marital sub-models (see Duley, 1989, for a detailed exposition), the main features of which will now be described.

2.1 The marriage and cohabitation model

The model adopted to handle pair formation at the micro-level is an extension of the developed by Clarke (1986), and adopts an open market, whereby migration is directly incorporated: individuals are free to migrate to find their spouse or cohabitee, with the result that individuals are added to or deleted from the population depending on the direction of the flow. The algorithm for marriage and cohabitation and its consequent events is set out in Figure 2. There were three stages: (1) testing each individual in the population for eligibility, with different criteria enabling different nuptial paths to be tracked; (2) testing the eligible individuals for marriage or cohabitation, with different events tested to cater for the different eligibility groups; and (3) matching selected individuals with partners and working out the consequent location decisions for both partners. Having divided prospective partners by sex, this step models the search for suitable partners in the local marriage and cohabitation market. The matching algorithm is based on the age combination of the potential partners at union.

Based on five year age group of a base partner, whose gender is selected at random, an imaginary partner (spouse or cohabitee) is generated with a given age. Then a match of this imaginary person with a locally available person from the relevant partner pool is attempted. If a local partner fitting the age-sex requirement is found a match is made and the two individuals are united and removed from their respective partner pools. If there is no suitable partner locally available then an interface with the wider marriage/cohabitation market outside the small area is necessary.

This interface results in either the export of the local individual and their removal from the pool, or the import of an "exotic" partner of the required age and sex. The decision to import or export individuals to satisfy the partner search is based on the annually adjusted local in- and out-migration propensities of individuals by age and sex. Gross figures are used so that there will be a combination of in- and out-migration motivated by marital transitions, although their ratio will reflect the dominant flow.

When the match has been completed, the newly formed couple must then be allocated to a house. The procedure adopted depends on the involvement of migration in the matching process. Out-migration of a local partner or in-migration of an "exotic" partner requires straightforward accounting. When both partners are locally resident the match will result in movement, unless it is the marriage of an already cohabiting couple. Either one partner or both partners can move. One would expect most newly formed couples to want to set up a new household, unless one or other is already living in a suitable household, taken as a single person household or lone parent household without other adults. In some cases this may not be possible, in which event they locate in one or other of their existing households.

We sought to combine these choices and restrictions into a two stage algorithm. In stage one, couples are given the opportunity to set up in a new conjugal household, that is to move to a vacant housing unit in the area. This is determined on the basis of housing requirement (number of persons, new couple plus dependent(s) where applicable), from which suitable housing provision is set (tenure and number of rooms). Local vacant housing stocks are then searched and if a suitable dwelling is found the new couple is assigned to it. If no suitable vacant housing unit is available, in stage two, movement is restricted to one of the two partners so that the couple or family is formed in an existing household, with no new household being established.

2.2 The divorce and dehabitation model

The modelling of pair dissolution is more straightforward than that of marriage, in that no matching algorithm is required since it is this match that is split through the divorce or dehabitation process. However, the implications of pair dissolution are equally complex. Breakup is sampled on the basis of age, sex and ethnic group of the base partner, with sex having been first set at random to avoid gender bias. Certain assumptions concerning the outcome of the divorce/dehabitation transition were made. The first was that the male former partner invariably departs from the existing household and having left is deemed to set up a new single person household. Given the small area approach, the location of this new household is dependent on the availablity of suitable vacant housing (cf.marriage and cohabitation model), with out-migration following an unsuccessful search. The second assumption is that the female former partner and any child(ren) remain in their present dwelling unit with updated attributes reflecting their new circumstances. Both former partners become eligible for remarriage.

3. THE MIGRATION OF WHOLE HOUSEHOLDS AND INDEPENDENT INDIVIDUALS WITHIN AND OUT OF AN AREA

In this section of the paper, the methods used to estimate the various migration probabilities used in the microsimulation model are described. In order, we discuss

(1) the estimation of mobility probabilities for wholly moving households;

(2) the estimation of mobility probabilities for independently moving individuals;

(3) the estimation of the probabilities of staying in an area or out-migrating; and

3.1 Mobility probabilities for wholly moving households

The target variable to be estimated is as follows:

$ph^{ta}_{s}(y)$ = probability that a household of type t with a head in age group a living in postal sector s migrates in year y.

By "migrates" is meant "makes a migration of the transition type over a single year". The term "mobility" indicates that no spatial boundaries are placed on the migrations involved: they can be moves within the area or out of it. The double classification by household type and age of head is used to capture two important influences on household mobility. Table 1 lists the age groups and household types employed in the UPDATE model.

The steps undertaken to estimate household mobility probabilities are as follows.

(1) Initial district estimate. The mobility probabilities for households in 1980-81 (the year prior to the Census), classified by type of household and age of head are estimated for the district containing the postcode sector of interest.

(2) Spatial adjustment factor. This mobility probability is adjusted up or down to reflect mobility in the particular postcode sector of interest.

(3) Temporal adjustment factor. This adjusted mobility probability is further adjusted up or down to reflect changes in mobility between 1980-81 and the current year of interest.

(4) Mobility probability due to demolition. To this adjusted mobility probability is added an additional mobility probability reflecting moves forced on households as a result of housing demolitions in the particular postcode sector of interest.

In other words,

$$ph^{ta}_{s}(y) = \text{initial district estimate}$$
$$\times \text{ spatial adjustment factor}$$
$$\times \text{ temporal adjustment factor}$$
$$+ \text{ mobility probability due to demolition} \qquad (1)$$

How estimates of each of these elements are achieved is now described.

3.1 The initial district estimate. The target variable to be estimated is

$ph^{ta}_{d}(81)$ = the probability that a household of type t with a head in age group a living in district d migrates in the year prior to the 1981 Census

which may be approximated as

$$ph^{ta}_{d}(81) = MH^{ta}_{d}(81) \;/\; H^{ta}_{d}(81) \qquad (2)$$

where

$MH^{ta}_{d}(81)$ = households of type t and head's age a in district d who move in the census year 1980-81

$H^{ta}_{d}(81)$ = all households of type t and head's age a in district d

Neither of these variables is directly available from published sources, but single classifications of households by type and by head's age are available at the district level from Migration Regional Reports and the MATPAC system for migrant households, and from County Reports for all households. A national table cross-classifying households by type and head's age is also available.

To estimate the variables on the right hand side of equation (2), the widely used technique of Iterative Proportional Fitting (IPF) is employed (see Fienburg 1970 and Birkin 1987 for more details).

Table 2 lays out the IPF computations for all households. A joint probability matrix for Great Britain in Table 2(a) is adjusted bi-proportionally to fit row and column marginal totals in Table 2(b) and 2(c) to yield a best estimate in Table 2(d) for the number of households in Leeds district by household type and age group of head.

Table 3 shows the IPF computations for estimating the number of mobile (and stayer) households, using the results of the previous estimation (Table 3c) and two district marginals classifying households by mobility status (mobile/stayer) and head's age (Table 3a) and household type (Table 3b). In this case tri-proportional fitting is needed to yield a best estimate array in Table 3(d) from which the requisite mobility probabilities can be computed.

Table 3(e) presents the household mobility probabilities for Leeds district. The most mobile households are those with younger heads (16-29 years) with a gradient of declining mobility with age, (roughly a 50% reduction in mobility between each age group), with very low rates in pensioner households. The age gradient is strongly apparent for all household types. However, there are noticeable differences in mobility rates between types. Mobility is highest amongst single person households (types 1 and 2), with one third of lone adults aged 16-29 moving the previous year. Of family households, those with lone parents are most mobile (type 3). Of married couple family households (types 4, 5, 6 and 7) those with no children under 16 are most migratory, with mobility declining with increased household size. Of the remaining types (types 8 and 9) multi-adult, non- or lone parent-family households, mobility corresponds more to that of married couples, suggesting the stabilising effect of larger household size.

3.1.2 The spatial adjustment factor. The district estimates need adjustment when used for individual postcode sectors. Mobility rates for households and for the whole population can be computed from data in the Small Area Statistics of the 1981 Census

$$mh_s(81) = \Sigma_e \, (MH_e(81) \;/\; H_e(81)\,) \qquad (3)$$

where

$mh_s(81)$ = the mobility rate for postcode sector s in 1980-81

$MH_e(81)$ = the number of wholly moving households (i.e. with a different address at the 1981 Census than one year earlier) in enumeration district e

$H_e(81)$ = the total number of households in enumeration district e.

The summation in equation (3) is over all enumeration districts which have been assigned to a postal sector. Enumeration districts were allocated to postal sectors by centroid matching checked by map inspection. The adjustment factor applied to the district mobility probabilities is the ratio of the sector mobility rate to that for the district d,

$$\text{spatial adjustment factor for postal sector } s = mh_s(81) \;/\; mh_d(81) \qquad (4)$$

To obtain a better understanding of the geography of mobility in Leeds, Figure 3 maps out these mobility rates. The district wide figure is just over 9%, yet sector figures range from over 25%

to less than 5%. To ignore such small area variation is to disregard intra-urban relocation, a fundamental element of small area migrant flows. The highest mobility rates are found in the inner city, apart from one or two outlying areas where new housing estates were developed in the year prior to the Census.

3.1.3 <u>The temporal adjustment factor</u>. Recent research using patient re-registration data from the NHSCR published by OPCS (Stillwell, Boden and Rees 1988) has established that migration rates in Britain have varied very substantially over time, rising in the 1980's from low values from 1980-81 to 1982-83 to a peak in 1987-88 with some recession since then. from the NHSCR derived migration data series can be computed out-migration rates for annual periods for Family Practitioner Committee (FPC) areas (which correspond in general to former metropolitan districts, shire counties and grouped London boroughs),

$$o_f(y) = O_f(y) \;/\; PAR_f(y) \qquad (5)$$

where $o_f(y)$ = out-migration for FPC area f in year y

$O_f(y)$ = total outflows of patients from FPC area f in year y

$PAR_f(y)$ = population at risk for FPC area f in year y.

The temporal adjustment factor is defined as the ratio of the out-migration rate for year y of interest to that in the year prior to the Census in 1981:

$$o_f(y) \;/\; o_f(81).$$

3.1.4 <u>The mobility probability due to demolition</u>. At the small area scale, migration levels are determined not only by attribute-based mobility propensities (the mobility component) but also by changes in local housing stock, that is, by the number of new dwellings constructed and existing dwellings demolished. Clearly, the construction of a new housing estate or the demolition of a 1960s flat complex will have a sudden and major impact of movement into and out of small area. Data on housing unit dynamics are available quarterly at local government level (Local Housing Statistics, England and Wales produced by the Department of the Environment). Although this is a valuable total constraint, the UPDATE model requires housing unit constructions and demolitions at the more detailed spatial scale of the postal sector.

Table 4 presents estimated postal sector housing unit demolitions and constructions for the period April 1981 to September 1986, computed from Leeds City Planning Department ward figures. An annual figure can be estimated by the simple deconsolidation of the 6 year aggregate. Not only has there been a small but significant increase in Leeds housing stocks, but more importantly, there has been considerable local variation in stock changes, ranging from large scale demolitions to equally large-scale new housing constructions. Broadly, there has been a net reduction in stocks in inner urban areas and net expansion in suburban housing stocks.

The mobility probability due to housing demolitions can be estimated as

$$DU_s(y) \;/\; TU_s(y)$$

where $DU_s(y)$ = the number of housing units demolished in postcode sector s at the start of year y.

and $TU_s(y)$ = the total number of units in postcode sector s in year y

3.1.5 <u>The model for estimating mobility probabilities for wholly moving households</u>. We can now bring together the detailed defintions and estimates outlined in the four previous subsections to produce a more precise specification for the model that estimates the mobility probabilities for wholly moving households. Equation (1) becomes

$$
\begin{aligned}
ph^{ta}_{s}(y) = ph^{ta}_{d}(81) & \\
\times & \quad (mh_{s}(81) \;/\; mh_{d}(81)) \\
\times & \quad (o_{f}(y) \;/\; o_{f}(81)\;) \\
+ & \quad (DU_{s}(y) \;/\; TU_{s}(y)\;) \qquad (6)
\end{aligned}
$$

where postal sector s is contained within local government district d, which is either coincident with or contained within FPC area f.

This formulation can be applied to any postal sector in England and Wales, and with a little modification to any postal sector in Scotland (where Area Health Boards are the equivalent of English or Welsh FPCs).

Table 5 illustrates the result of the spatial, temporal and stock adjustment for postcode sector, LS6 1. Rates are considerably higher than those for the district, which is in line with the picture provided in the Census in Figure 3. Mobility rates fall slightly from their 1981 level in 1982 and 1983 but then pick up again from 1984. From Table 4 one can see that the impact of housing stock dynamics is very minor, with only 130 housing units out of a 1981 stock total of 5285 demolished over the six year period (2.5%) and a net change in housing stocks of +12 (less than 0.25%).

3.2 Mobility probabilities for independent individuals

For each household that does not move as a whole, each eligible household member is exposed to a rate of moving as an individual or as part of a unit smaller than a household. Eligibility for "independent" mobility excludes children under 16 and members of formal and informal couples, whose migration related to pair dissolution is modelled separately in the BREAKUP module.

Similar steps to those employed for wholly moving households are used to estimate individual mobility probabilities, with the exclusion of the housing stock component. The target variable to be estimated is as follows:

$pi^{agm}_{s}(y)$ = probability that an independent individual of age a, gender g, marital status m in postal sector s migrates in year y.

This probability is estimated as follows:

$pi^{agm}_{s}(y)$ = initial district estimate
x spatial adjustment factor
x temporal adjustment factor
x reduction factor to reflect prior migration in the pair formation and dissolution process (7).

3.2.1 <u>The initial district estimate</u>. An estimate of the probability of migration for independent individuals at district level involves the subtraction of non-eligible individuals from both the migrant count of individuals and from the population divisor. All household heads and their <u>de facto</u> spouses were deleted. Full details are given in Duley (1989, Chapter 7, section 7.2.5). The initial district estimate was adjusted downwards by the ratio of reported "independent" or "lone" migrants to the reduced number of migrants:

$$pi^{agm}_{d}(81) = (MiR^{agm}_{d}(81) \;/\; PiR^{agm}_{d}(81)) \times (\text{total lone migrants} / \Sigma_{a} \Sigma_{g} \Sigma_{m} MiR^{agm}_{d}(81)) \quad (8)$$

where

$pi^{agm}_{d}(81)$ = the probability that independent individuals of age a, gender g and marital status m in district d migrate in 1980-81

$MiR^{agm}_{d}(81)$ = an estimate of the reduced number of individuals of age a, gender g and marital status m in district d who carried out "independent" migration in 1980-81

$PiR^{agm}_{d}(81)$ = an estimate of the reduced number of individuals of age a, gender g and marital status m in district d eligible for "independent" migration in 1980-81.

3.2.2 The spatial adjustment factor. The district probability was adjusted to reflect postcode sector mobility rates by multiplication by the ratio of sector to district migration rates for persons

$$(mi^{bgn}_{s}(81) \ / \ mi^{bgn}_{d}(81))$$

where $mi^{bgn}_{s}(81)$ is the rate of migration of age b, gender g, marital status n in sector s in 1980-81. The age classification available, signified by use of the letter b, was an aggregated one (16-24, 25-34, 35-44, 45-59, 60-64, 65+), as was the marital status classification, signified by the use of the letter n (married, single and widowed/divorced).

3.2.3 The temporal adjustment factor. The same factors were used as described for wholly migrating households (section 3.1.3). It is necessary to specify the method for estimating migration probabilities at this stage as follows:

$$pi^{agm}_{s}(y) = pi^{agm}_{d}(81) \times (mi^{agm}_{s}(81) \ / \ mi^{agm}_{d}(81)) \times (o_{f}(y) \ / \ o_{f}(81)) \qquad (8)$$

Table 6 shows the results of this estimation for the Leeds postal sector LS6 1.

3.2.4 The reduction factor to allow for prior migration in the pair formation and dissolution process. Account must be taken of "independent" individual migration already modelled in the pair formation and dissolution process. The number of such migrants is counted as the model runs and expressed as a ratio to the total number of persons migrating, and this is subtracted from unity:

$$\text{reduction factor} = [1 - (PM^{agm}{}_{s}(y)/TM^{agm}{}_{s}(y))] \qquad (9)$$

where $PM^{agm}{}_{s}(y)$ = the number of "pair" migrants of age a, gender g and marital status m simulated during pair formation and dissolution who move from postcode sector s in year y

$TM^{agm}{}_{s}(y)$ = total number of migrants of age a, gender g and marital status m expected to migrate in postcode sector s in year y.

3.2.5 The model for estimating mobility probabilities for independent individuals. The total number of migrants is estimated by multiplication of the probabilities defined in equation (9) by the local, small area population at risk. Using the reduction factor defined in equation (9) produces the final estimate of the mobility probabilities for "independent" individuals:

$$\begin{aligned} pi^{agm}{}_{s}(y) = {} & pi^{agm}{}_{d}(81) \\ & \times \; (\; mi^{agm}{}_{s}(81) \; / \; mi^{agm}{}_{d}(81) \;) \\ & \times \; (\; o_{f}(y) \; / \; o_{f}(81) \;) \\ & \times \; [\; 1 - (PM^{agm}{}_{s}(y) \; / \; TM^{agm}{}_{s}(y) \;] \qquad (10). \end{aligned}$$

3.3 The probabilities of relocation within an area and of out-migration

3.3.1 The mobility pool. The first pass through the list of simulated households generates a pool of moving households and fissioned part households (mainly individuals), which will search for suitable housing vacancies in the local housing market. To allocate migrants to housing units it is necessary to distinguish between moves within the area and moves to the outside world. The within area movers compete for housing units in the small area, but movers out of the area release units for occupation by in-migrants.

3.3.2 <u>The probabilities of staying and leaving</u>. Households and independent individuals for whom a migration has been simulated must therefore be allocated a destination inside or outside the small area of interest by sampling the appropriate probabilities of staying and leaving. If a matrix of intra- and inter-area flows is known, probabilities of relocation within an area or outside it given mobility can be computed:

$$\mathrm{pr(staying)} = M_{ii} \;/\; S_j \; M_{ij} \qquad (11)$$

and

$$\mathrm{pr(leaving)} = \Sigma_{j \neq i} \; M_{ij} \;/\; S_j \; M_{ij} \qquad (12)$$

where M_{ij} = the number of migrants from origin i to destination j. However, such a matrix of inter-area flows exists only for one set of areas, namely within district wards. We need therefore to develop a method of using this information to make an estimate at an alternate spatial scale.

3.3.3 <u>A production constrained spatial interaction model</u>. The method comprises the following steps.

(1) An origin-specific, production-constrained spatial interaction model (SIM) is fitted to the observed inter-ward migration matrix (derived from OPCS's Special Migration Statistics from the 1981 Census using the MATPAC program). The model takes the form

$$M_{ij} = A_i \; O_i \; W_j \; \exp(-\mathrm{beta}_i \; d_{ij}) \qquad (13)$$

where $O_i = \Sigma_j M_{ij}$ = total migrants originating in ward i

$W_j = \Sigma_i M_{ij}$ = attractiveness of ward j to migrants

$beta_i$ = distance decay parameter for ward i

d_{ij} = the distance between ward i and ward j

$A_i = 1 / \Sigma_j W_j \exp(-beta_i d_{ij})$ = balancing factor for ward i.

The IMP program of Stillwell (1984) was used to estimate the $beta_i$ values. The values for Leeds wards are shown in Table 7(a).

(2) These ward beta parameters are used to estimate the equivalent parameters for postcode sectors by inputting the ward values to constituent enumeration districts and then computing a weighted average for enumeration districts lying within a postal sector, employing enumeration district populations as weights. These imputed beta values for postcode sectors are given in Table 7(b).

(3) An inter-sector distance matrix is computed from knowledge of sector centroids and Pythagoras' theorem. Intra-sector distance is assumed to be

$$d_{ii} = (A_i / pi)^{0.5} \qquad (14)$$

where A_i is the area of postal sector i.

(4) The production-constrained SIM is used to predict the share of out-migration from each sector to itself

$$M_{ii} / O_i = W_i \exp(-beta_i d_{ii}) / \Sigma_j W_j \exp(-beta_i d_{ij}) \qquad (15)$$

where Wi and Wj are the attractiveness variables for postal sectors i and j which are set equal to the migration within or into the sector estimated by summing that variable available for enumeration districts.

(5) So the probability of staying in an area given mobility is computed by the left hand side of equation (15), while the probability of leaving the area is 1 minus the probability of

staying. Table 8 presents the within/without dichotomy for Leeds postal sectors. The variation is considerable, ranging from near negligible intra-area flows within LS 1 to large and in some cases dominant flows within peripheral postal sectors, those in LS21 and LS22, for example. Such a distribution can be explained broadly on the basis that migrants have further to travel to cross boundaries in the larger peripheral postal sectors. However, this relationship is constrained somewhat by local housing stock that increases the attractiveness of the destination sector, and intervening opportunities that reduce the distance of moves.

Within area movers are then matched to vacant dwellings in the housing pool of the small area. Their successful matching is based on a probabilistic matching of their respective attributes: housing provision versus housing requirement (size of household - size of unit; disposable household income - purchase price/rantal value). The mechnaisms for such matching, the links between housing units, households and /or individuals is provided by pointers or common reference numbers.

4. THE ESTIMATION AND RECONSTRUCTION OF IN-MIGRANT HOUSEHOLDS AND INDIVIDUALS

4.1 The estimation of in-migrant numbers

The units in the housing pool not taken up by moving hosueholds, and housing spaces within existing households not taken up by moving individuals resident at the start of the time inetrval are then available for occupation by new, in-migrating households and individuals.

Central to the modelling of migration at the small area scale is the role of the "pull" of vacant housing stock. Very simply, migrants can only move into an ara if there are housing spaces for them to occupy (ignoring the migration of the homeless). It follows that the most significant changes in household and population counts will be caused by changes in housing stock.

To estimate in-migrant numbers one again distinguishes between mobility and housing stock components. Due to the total absence of small area migration data for years after 1981 and the effect of boundary definition and spatial scale on mobility levles, simplifications that no net migration efect on household numbers is induced by the mobility component. That is, all housing units left vacant by out-migrating households will be filled by in-migrant households. To this total must be added the new housing component. Assuming that all new housing completions are occupied within one year of construction, this additional annual sum corresponds to the number of housing completions. The annual in-migrant household sum is of the form:

$$\text{Total number of in-migrant households} = \begin{array}{c}\text{number of mobile}\\ \text{in-migrant}\\ \text{households}\end{array} + \begin{array}{c}\text{number of new}\\ \text{housing units}\\ \text{constructed}\end{array} - \begin{array}{c}\text{number of old}\\ \text{housing units}\\ \text{demolished}\end{array} \qquad (16).$$

Table 9 illustrates the form that the migrant household accounts take.

4.2 Assigning personal and relational attributes to in-migrants

Finally, the characteristics of in-migrant households and individuals must be determined. In part this is dependent on the particular nature of migrants and in part on the particular nature of the small area population. The size and composition of in-migrants households is determined in part by those of the housing units and in part by the collective demographic and socio-economic character of the small area. The detailed reconstruction of the in-migrant population is carried out using modified versions of the techniques used to reconstruct the starting stock of households and individuals in the small area. Full details are given in Duley (1990, section 7.2.8).

5. IMPLEMENTING MIGRATION IN THE MICROSIMULATION MODEL

How are the probability distributions described in the third section of the paper and the in-migrant numbers described in the fourth section handled in the microsimulation? Two figures show how the results of the estimation work are used. Figure 4 highlights stages in the modelling of the mobility and destination processes, while Figure 5 sets out the stages involved in adding in-migrants to the small area population.

5.1 The testing of existing households and eligible individuals for mobility

Each household in the small area is tested for migration as a whole, using the standard Monte Carlo sampling technique. Testing is carried out on the basis of the age of the head and the type of household comprising the "whole". If movement is deemed to occur, the household is placed in a pool of migrant households. The associated housing unit, previously occupied, is added to the vacant housing pool becoming eligible for reoccupation. The next household is then processed and so on. If the household is deemed to stay, and is not a single person household, eligible individuals within it are tested for independent migration on the basis of their age, sex and marital status. Such individuals are confined to non-family adults and non-dependent children. Members of formal and informal unions are excluded due to the separate modelling of their migration associated with pair dissolution in the BREAKUP module. It follows that new non-family adults generated due to couple breakup are also excluded. If the eligible individual is deemed to move, he or she is placed in an individual migrant pool, with the household size and composition updated to relect new household conditions.

5.2 The destination selection of migrant households and individuals

Firstly, each individual in the "independent" migrant pool is assigned a destination, sampling from a local distance function. If deemed to migrate to a destination outside the small area the individual is deleted. If deemed to remain within the small area (destination zone the same as the origin zone) the individual must be assigned to a vacant space within an existing household. Assignment is based on the random selection of the composition of the destination household. The local household list is then searched until a suitable household is found. Where the addition of another household member means that a household density criterion is exceeded, then the addition is excluded. This ensures that households do not become unrealistically overcrowded. Like the origin household, the household size and composition of the destination household is updated to match the new household structure.

Secondly, before migrant households can be processed, existing or newly vacant housing units must be processed for demolition and new units added through construction. In line with the relevant count for the period, housing units are randomly deleted from the vacant pool. Similarly, given the known construction count, new housing units are generated and added to vacant housing stocks. Tenure is determined first from which number of rooms and amenity provision are assigned.

Thirdly, each household in the migrant pool is assigned a destination, sampling from the same local distance function applied to individuals. If deemed to leave the area, the household and its members are deleted from the local lists, with the running out-migrant household total being incremented by one. If deemed to stay within the area, the household is assigned to a vacant housing unit. "Imaginary" tenure and number of rooms are generated given the household type of the mobile household. Local vacant housing stocks are then searched to find a "real" housing unit with the required attributes, which is then matched with the homeless household, and removed from the vacant housing pool.

5.3 The simulation of the number of in-migrant households and individuals and their characteristics

Firstly, in-migrant households are simulated. Given the distinction of "mobile" and "stock" based in-migrant households this task is split into two. Adopting the assumption that there is not net migration effect on household numbers induced by the mobility component, "mobile" in-migrant numbers are computed from out-migrant numbers reduced in line with demolitions of existing housing units (stock push effect). The migrant character of these households is established next. The in-migrant households are distributed amongst the type and age of head groups using local estimates. Proceeding through each age-type combination, each household assigned to it is then fully reconstructed (cf. population reconstruction). First, household type is converted to a corresponding broad household composition category (summing with/without others) for parity with the household classification adopted in the UPDATE model. The remaining attributes of the head are generated next. Then in all but single person households, remaining member(s) of the household are generated on the basis of the household composition set, which predefines the path of household membership simulation. Finally, each new household is assigned to a vacant housing unit. As with internal migrant households, assignment is carried out by matching "imaginary" and "real" units with suitable tenure and unit size given household type, the unit being removed from the vacant housing pool.

"Stock" based in-migrant households are processed next, equal to new unit construction. The household simulated must fit the housing unit. In this case, household type is determined first given tenure and size of the new unit, from which the age group of the head is ascribed. The household type is then converted to its respective compositional group, with the detailed membership simulation continuing in the same manner as for "mobile" in-migrant households.

Then, in-migrant individuals are simulated. Given that we are unable to model the link between spaces within existing households (supply) and "independent" migrants searching for accommodation (demand), simulation is performed on the basis of local in-migration estimates applied to current small area population (at risk) by age, size and marital status. Each "independent" in-migrant so generated is assigned to vacant spaces within existing households following the mechnaism of internal migration updating the attributes of the destination household accordingly.

5.4 Conclusions

There is a strong tradition of using microsimulation models to study the changing geography of population (Hagerstrand 1957; Morrill 1965; Woods 1981). The focus in previous work has been on migration occurring in a fine network of areas to a simply classified population of individuals. The focus in this work has been on tracing the migration behaviour of a richly classified set of households and associated individuals in a rather simple set of areas. In so doing migration has been regarded as the outcome of several important processes which interface intimately with both the marriage and housing markets, In common with the earlier geographic tradition, we have had to think imaginatively of ways in which the probabilities and numbers required in the microsimulation process can be estimated. The estimation procedures have been presented in some detail. The results of the estimation have considerable interest in themselves, but in the case of the present work are seen only as means to a more ambitious end, that of updating the population of small areas within cities or counties between Censuses, retaining a good proportion of the richness of character available in those decennial, national endeavours.

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TABLE 1. The household mobility variable and associated classifications

Variable	Definition
target variable	
$ph^{ta}_{s}(y)$	mobility probability for households of type t with heads in age group a in postcode sector s in year y
subscript classification	
t	(1) 1 adult 60/65+ with no children under 16 (2) 1 adult under 60/65 with no children under 16 (3) 1 adult any age with child(ren) under 16 (4) 2 adults (married male with married female) with no children under 16 (5) 2 adults (married male with married female) with children under 16 (6) 3+ adults (married male(s) with married female(s) with or without others) with no children under 16 (7) 3+ adults (married male(s) with married female(s) with or without others) with children under 16 (8) other adults (2+) with no children under 16 (9) other adults (2+) with children under 16
a	16-29, 30-44, 45-64, 65+
s	111 postcode sectors of Leeds metropolitan district
y	1980-81, 1981-82, 1982-83, 1983-84, 1984-85, 1985-86 (mid-year to mid-year annual periods)

TABLE 2. The estimation of household numbers by age group of head and household type for Leeds district

(a) national data: households by age of head and type [1]

household type	16-29	30-44	45-64	65+	all ages
1	0.0000	0.0000	0.0000	0.1416	0.1416
2	0.0167	0.0203	0.0387	0.0000	0.0757
3	0.0075	0.0109	0.0024	0.0003	0.0211
4	0.0275	0.0277	0.0944	0.0954	0.2450
5	0.0572	0.1278	0.0241	0.0007	0.2098
6	0.0013	0.0110	0.0856	0.0192	0.1171
7	0.0030	0.0341	0.0413	0.0025	0.0809
8	0.0129	0.0130	0.0257	0.0343	0.0859
9	0.0045	0.0111	0.0062	0.0012	0.0230
all types	0.1306	0.2559	0.3183	0.2952	1.0000

(b) district marginal 1: households by type [2]
(c) district marginal 2: households by age of head [3]

household type	16-29	30-44	45-64	65+	all ages	probability
1					41288	0.1571
2					22791	0.0867
3					6436	0.0245
4					63941	0.2433
5					51463	0.1958
6					28265	0.1075
7					19758	0.0752
8					22143	0.0843
9					6721	0.0256
all types	33531	67048	95069	67158	262806	1.0000
probability	0.1276	0.2551	0.3618	0.2555	1.0000	-

(d) district estimate; households by age of head and type

household type	16-29	30-44	45-64	65+	all ages	probability
1	0	0	0	41288	41288	0.1571
2	4532	5874	12384	0	22790	0.0867
3	2182	3384	822	48	6436	0.0245
4	7735	8333	31302	16571	63941	0.2433
5	13230	31560	6566	106	51462	0.1958
6	281	2634	22682	2668	28265	0.1075
7	663	8026	10733	336	19758	0.0752
8	3649	3943	8566	5985	22143	0.0843
9	1247	3267	1997	210	6721	0.0256
all types	33519	67021	95052	67212	262804	1.0000
probability	0.1275	0.2550	0.3617	0.2558	1.0000	-

Source: 1 adjusted OPCS, 1983b, Table 26 (HH)
2 OPCS, 1983a, Table 39 (CR 45)
3 OPCS, 1983a, Table 35 (CR 45)

TABLE 3. The estimation of mobile and stayer household numbers by age group of head and household type for Leeds district

Input

(a) district marginal 1:
mobile/stayer households by age of head[1]

household status	age group of head 16-29	30-44	45-64	65+
mobile	6174	5092	3341	2110
stayer	27357	61956	91728	65048

(b) district marginal 2: mobile/stayer households by type [2]

household status	household type 1	2	3	4	5	6	7	8	9
mobile	1606	3390	892	3319	4407	751	758	1072	522
stayer	39682	19401	5544	60622	47056	27514	19000	21071	6199

(c) district marginal 3: households by age of head and type [3]

household type	age group of head 16-29	30-44	45-64	65+
1	0	0	0	41288
2	4532	5874	12384	0
3	2182	3384	822	48
4	7735	8333	31302	16571
5	13230	31560	6566	106
6	281	2634	22682	2668
7	663	8026	10733	336
8	3649	3943	8566	5985
9	1247	3267	1997	210

Output

(d) district estimate: mobile/stayer households by age of head and type

household	age group of head 16-29		30-44		45-64		65+	
type	move	stay	move	stay	move	stay	move	stay
1	0	0	0	0	0	0	1606	39682
2	1484	3048	947	4928	959	11426	0	0
3	498	1685	353	3031	40	782	1	47
4	1299	6436	615	7718	1052	30250	353	16219
5	2061	11169	2142	29419	202	6364	2	104
6	35	247	139	2495	538	22145	40	2628
7	81	582	419	7607	252	10480	5	331
8	505	3144	235	3708	231	8336	102	5883
9	209	1038	241	3026	67	1929	4	205

(e) probability of a household resident in Leeds district in 1981 "wholly moving" by age of head and type

household type	age group of head 16-29	30-44	45-64	65+
1	0.0000	0.0000	0.0000	0.0389
2	0.3275	0.1612	0.0774	0.0000
3	0.2280	0.1044	0.0484	0.0309
4	0.1679	0.0738	0.0336	0.0213
5	0.1558	0.0679	0.0308	0.0195
6	0.1235	0.0527	0.0237	0.0150
7	0.1226	0.0522	0.0235	0.0148
8	0.1383	0.0596	0.0269	0.0170
9	0.1679	0.0738	0.0336	0.0213

source:
1 MATPAC Table 1.5 (DT 6924U); OPCS, 1983a, Table 35 (CR)
2 OPCS, 1984, Table 6 (RM 7)
3 Estimate, see Table 2

TABLE 4. Housing unit accounts for postcode sectors, Leeds, 1981-86

sector label	1981 housing stock	4/1981-9/1986 housing unit +	-	net	sector label	1981 housing stock	4/1981-9/1986 housing unit +	-	net
LS1 2	49	2	1	1	LS22 4	3481	271	0	271
LS1 3	46	3	4	-1	LS22 5	879	68	0	68
LS1 4	157	9	12	-3	LS23 6	2575	200	0	200
LS1 5	0	0	0	0	LS23 7	292	23	0	23
LS1 6	27	1	0	1	LS24 9	136	11	0	11
LS10 1	1060	95	169	-74	LS25 1	3094	102	28	74
LS10 2	2263	236	415	-179	LS25 2	2663	88	24	64
LS10 3	5166	464	681	-217	LS25 3	521	24	0	24
LS10 4	4424	227	2	225	LS25 4	700	32	0	32
LS11 0	1996	51	10	41	LS25 5	67	3	0	3
LS11 5	2651	74	17	57	LS25 7	3550	162	0	162
LS11 6	2315	81	25	56	LS26 0	4895	54	0	54
LS11 7	3626	80	11	69	LS26 8	4435	87	17	70
LS11 8	3223	101	27	74	LS26 9	1416	42	11	31
LS11 9	1443	59	21	38	LS27 0	2693	149	9	140
LS12 1	1984	65	68	-3	LS27 7	3283	107	2	105
LS12 2	2482	61	135	-74	LS27 8	3050	176	11	165
LS12 3	3362	91	123	-32	LS27 9	2435	91	3	88
LS12 4	3325	110	7	103	LS28 5	4297	81	0	81
LS12 5	3588	115	2	113	LS28 6	1748	61	11	50
LS12 6	872	29	2	27	LS28 7	3656	55	0	55
LS13 1	2480	89	17	72	LS28 8	2986	39	0	39
LS13 2	4777	212	137	75	LS28 9	2084	23	0	23
LS13 3	3671	198	60	138	LS29 6	149	6	0	6
LS13 4	4249	88	81	7	LS3 1	948	55	73	-18
LS14 1	3427	58	0	58	LS4 2	3848	192	45	147
LS14 2	1451	105	0	105	LS5 3	3193	153	48	105
LS14 3	966	51	0	51	LS6 1	5285	142	130	12
LS14 5	3627	262	0	262	LS6 2	2977	123	152	-29
LS14 6	5626	4	9	-5	LS6 3	4257	120	71	49
LS15 0	3687	179	72	107	LS6 4	3534	57	1	56
LS15 4	2043	118	0	118	LS7 1	1382	80	106	-26
LS15 7	3878	253	9	244	LS7 2	3432	110	45	65
LS15 8	3724	402	0	402	LS7 3	4074	152	21	131
LS15 9	337	37	0	37	LS7 4	2842	109	24	85
LS16 5	2812	61	7	54	LS8 1	3754	94	8	86
LS16 6	4007	258	1	257	LS8 2	4599	126	15	111
LS16 7	4347	422	0	422	LS8 3	4506	46	2	44
LS16 8	1267	120	0	120	LS8 4	2409	56	6	50
LS16 9	1227	20	0	20	LS8 5	3885	110	111	-1
LS17 5	3848	196	0	196	LS9 0	3288	34	100	-66
LS17 6	3850	97	0	97	LS9 6	5489	17	47	-30
LS17 7	3688	279	0	279	LS9 7	4100	106	144	-38
LS17 8	3662	223	4	219	LS9 8	1703	17	44	-27
LS17 9	1210	94	0	94	LS9 9	2257	24	71	-47
LS18 4	3635	70	0	70	BD10 0	0	0	0	0
LS18 5	3540	69	0	69	BD11 1	1780	54	1	53
LS19 6	2505	58	0	58	BD3 7	340	6	0	6
LS19 7	4999	182	0	182	BD4 8	630	7	0	7
LS2 8	320	18	25	-7	WF10 2	1679	77	0	77
LS2 9	720	41	55	-14	WF2 0	192	13	1	12
LS20 8	2362	93	0	93	WF3 1	2643	178	12	166
LS20 9	2008	79	0	79	WF3 2	1567	106	7	99
LS21 1	2008	33	0	33	WF3 3	2125	92	0	92
LS21 2	2330	38	0	38	WF3 4	207	2	0	2
LS21 3	2114	34	0	34	all pcs	282471	10907	3608	7299

TABLE 5. The probability of a household "wholly moving" from a small area, 1981-86, the example of Leeds postal sector LS6 1

	age of head	household type[1] 1	2	3	4	5	6	7	8	9
1	16-29	0.000	0.807	0.563	0.416	0.386	0.307	0.305	0.343	0.416
9	30-44	0.000	0.399	0.260	0.185	0.171	0.133	0.132	0.150	0.185
8	45-64	0.000	0.194	0.123	0.087	0.080	0.062	0.062	0.070	0.087
1	65+	0.100	0.000	0.080	0.056	0.052	0.041	0.041	0.046	0.056
1	16-29	0.000	0.760	0.530	0.392	0.364	0.289	0.287	0.323	0.392
9	30-44	0.000	0.376	0.245	0.174	0.161	0.126	0.125	0.142	0.174
8	45-64	0.000	0.183	0.116	0.082	0.075	0.059	0.058	0.066	0.082
2	65+	0.094	0.000	0.075	0.053	0.049	0.039	0.038	0.043	0.053
1	16-29	0.000	0.742	0.518	0.383	0.355	0.282	0.280	0.316	0.383
9	30-44	0.000	0.367	0.239	0.170	0.157	0.123	0.122	0.138	0.170
8	45-64	0.000	0.179	0.113	0.080	0.074	0.058	0.057	0.065	0.080
3	65+	0.092	0.000	0.074	0.052	0.048	0.038	0.038	0.042	0.052
1	16-29	0.000	0.818	0.570	0.421	0.391	0.311	0.309	0.348	0.421
9	30-44	0.000	0.404	0.263	0.187	0.173	0.135	0.134	0.152	0.187
8	45-64	0.000	0.196	0.124	0.088	0.081	0.063	0.062	0.071	0.088
4	65+	0.101	0.000	0.081	0.057	0.053	0.041	0.041	0.046	0.057
1	16-29	0.000	0.840	0.586	0.432	0.401	0.319	0.317	0.357	0.432
9	30-44	0.000	0.415	0.270	0.192	0.177	0.138	0.137	0.156	0.192
8	45-64	0.000	0.201	0.127	0.090	0.083	0.064	0.064	0.073	0.090
5	65+	0.103	0.000	0.083	0.058	0.054	0.042	0.042	0.047	0.058
1	16-29	0.000	0.830	0.579	0.428	0.397	0.315	0.313	0.353	0.428
9	30-44	0.000	0.410	0.267	0.190	0.175	0.137	0.136	0.154	0.190
8	45-64	0.000	0.199	0.126	0.089	0.082	0.064	0.063	0.072	0.089
6	65+	0.102	0.000	0.082	0.058	0.053	0.042	0.041	0.047	0.058

Note: for classification of household type see Table 1

TABLE 6. The probability of an "independent" person migrating from a small area, 1981-86, the example of Leeds postal sector LS6 1

	age	male married	male single	male wid/div	female married	female single	female wid/div
	16-20	0.0136	0.0071	0.0069	0.0328	0.0082	0.0278
	21-24	0.0096	0.0136	0.0298	0.0190	0.0159	0.0320
1	25-29	0.0049	0.0144	0.0281	0.0098	0.0145	0.0204
	30-34	0.0030	0.0073	0.0148	0.0049	0.0032	0.0045
9	35-39	0.0020	0.0046	0.0119	0.0034	0.0021	0.0035
	40-44	0.0015	0.0045	0.0089	0.0025	0.0018	0.0026
8	45-49	0.0001	0.0020	0.0044	0.0030	0.0019	0.0030
	50-54	0.0001	0.0017	0.0033	0.0027	0.0017	0.0029
1	55-59	0.0001	0.0018	0.0020	0.0026	0.0018	0.0025
	60-64	0.0001	0.0016	0.0019	0.0025	0.0014	0.0022
	65-69	0.0015	0.0019	0.0021	0.0012	0.0011	0.0017
	70-74	0.0014	0.0022	0.0021	0.0010	0.0011	0.0017
	75+	0.0013	0.0019	0.0026	0.0011	0.0017	0.0021
	16-20	0.0157	0.0081	0.0080	0.0342	0.0086	0.0290
	21-24	0.0092	0.0131	0.0285	0.0174	0.0145	0.0293
1	25-29	0.0039	0.0116	0.0226	0.0090	0.0133	0.0188
	30-34	0.0025	0.0061	0.0123	0.0044	0.0029	0.0041
9	35-39	0.0020	0.0046	0.0119	0.0027	0.0017	0.0028
	40-44	0.0019	0.0055	0.0109	0.0030	0.0022	0.0031
8	45-49	0.0001	0.0021	0.0047	0.0022	0.0014	0.0023
	50-54	0.0001	0.0014	0.0027	0.0024	0.0015	0.0026
2	55-59	0.0001	0.0026	0.0028	0.0034	0.0023	0.0032
	60-64	0.0001	0.0018	0.0021	0.0034	0.0020	0.0031
	65-69	0.0010	0.0013	0.0015	0.0006	0.0005	0.0007
	70-74	0.0010	0.0016	0.0015	0.0008	0.0009	0.0014
	75+	0.0012	0.0017	0.0022	0.0013	0.0021	0.0026
	16-20	0.0142	0.0074	0.0072	0.0319	0.0080	0.0270
	21-24	0.0089	0.0126	0.0275	0.0167	0.0139	0.0281
1	25-29	0.0038	0.0111	0.0217	0.0091	0.0135	0.0191
	30-34	0.0022	0.0054	0.0109	0.0044	0.0029	0.0041
9	35-39	0.0024	0.0054	0.0142	0.0027	0.0017	0.0028
	40-44	0.0014	0.0043	0.0084	0.0030	0.0022	0.0031
8	45-49	0.0001	0.0018	0.0040	0.0028	0.0017	0.0028
	50-54	0.0001	0.0016	0.0030	0.0023	0.0015	0.0025
3	55-59	0.0001	0.0026	0.0028	0.0023	0.0016	0.0022
	60-64	0.0000	0.0008	0.0009	0.0031	0.0018	0.0027
	65-69	0.0010	0.0013	0.0015	0.0010	0.0009	0.0014
	70-74	0.0010	0.0016	0.0015	0.0009	0.0010	0.0015
	75+	0.0013	0.0019	0.0026	0.0016	0.0025	0.0030

	age	male married	male single	male wid/div	female married	female single	female wid/div
	16-20	0.0119	0.0062	0.0061	0.0265	0.0066	0.0225
	21-24	0.0098	0.0139	0.0304	0.0178	0.0149	0.0300
1	25-29	0.0049	0.0144	0.0282	0.0101	0.0150	0.0212
	30-34	0.0027	0.0067	0.0135	0.0047	0.0031	0.0043
9	35-39	0.0025	0.0059	0.0154	0.0048	0.0030	0.0050
	40-44	0.0017	0.0051	0.0101	0.0036	0.0026	0.0037
8	45-49	0.0001	0.0019	0.0041	0.0028	0.0017	0.0028
	50-54	0.0001	0.0021	0.0040	0.0027	0.0017	0.0029
4	55-59	0.0001	0.0025	0.0028	0.0032	0.0021	0.0030
	60-64	0.0001	0.0018	0.0020	0.0032	0.0018	0.0028
	65-69	0.0019	0.0024	0.0027	0.0013	0.0011	0.0017
	70-74	0.0019	0.0029	0.0028	0.0010	0.0011	0.0017
	75+	0.0014	0.0021	0.0028	0.0019	0.0030	0.0036
	16-20	0.0130	0.0067	0.0066	0.0271	0.0068	0.0230
	21-24	0.0098	0.0140	0.0306	0.0190	0.0159	0.0320
1	25-29	0.0049	0.0144	0.0281	0.0103	0.0153	0.0215
	30-34	0.0027	0.0067	0.0136	0.0053	0.0035	0.0049
9	35-39	0.0027	0.0062	0.0163	0.0044	0.0027	0.0046
	40-44	0.0019	0.0058	0.0114	0.0037	0.0027	0.0038
8	45-49	0.0002	0.0022	0.0049	0.0035	0.0021	0.0035
	50-54	0.0001	0.0020	0.0038	0.0026	0.0016	0.0027
5	55-59	0.0001	0.0027	0.0030	0.0030	0.0021	0.0028
	60-64	0.0001	0.0019	0.0022	0.0033	0.0019	0.0029
	65-69	0.0014	0.0017	0.0020	0.0013	0.0011	0.0017
	70-74	0.0017	0.0026	0.0025	0.0009	0.0009	0.0015
	75+	0.0014	0.0020	0.0028	0.0019	0.0031	0.0037
	16-20	0.0117	0.0060	0.0059	0.0244	0.0061	0.0206
	21-24	0.0096	0.0136	0.0298	0.0194	0.0162	0.0326
1	25-29	0.0051	0.0151	0.0296	0.0113	0.0168	0.0237
	30-34	0.0027	0.0066	0.0132	0.0050	0.0033	0.0046
9	35-39	0.0025	0.0058	0.0152	0.0045	0.0028	0.0047
	40-44	0.0020	0.0059	0.0117	0.0037	0.0026	0.0037
8	45-49	0.0002	0.0025	0.0055	0.0030	0.0018	0.0030
	50-54	0.0001	0.0019	0.0037	0.0025	0.0016	0.0027
6	55-59	0.0001	0.0027	0.0029	0.0033	0.0023	0.0031
	60-64	0.0001	0.0016	0.0019	0.0028	0.0016	0.0025
	65-69	0.0012	0.0015	0.0017	0.0014	0.0013	0.0019
	70-74	0.0016	0.0025	0.0024	0.0007	0.0007	0.0012
	75+	0.0016	0.0023	0.0031	0.0019	0.0030	0.0036

source: computed in UPDATE

TABLE 7. Best-fit origin-specific beta values for Leeds wards, and weighted estimates of corresponding betas for postal sectors

(a) wards

ward label	beta value	ward label	beta value	ward label	beta value
Aireborough	0.50470	Harehills	0.42681	Pudsey Nth	0.50175
Armley	0.43945	Headingley	0.41754	Pudsey Sth	0.53856
Barwk & Kipx	0.48386	Horsforth	0.46395	Richmond H	0.51260
Beeston	0.53033	Hunslet	0.76208	Rothwell	0.71714
Bramley	0.54200	Kirkstall	0.28774	Roundhay	0.26449
Burmantofts	0.35914	Middleton	0.72415	Seacroft	0.34526
Chap Allrtn	0.33196	Moortown	0.29405	University	0.35889
City & Holb	0.42565	Morley Nth	0.53837	Weetwood	0.29387
Cookridge	0.33437	Morley Sth	0.65828	Wetherby	0.61252
Garf & Swill	0.47769	North	0.53048	Whinmoor	0.36583
Halton	0.39596	Otley & Whf	0.74272	Wortley	0.43251

source: computed using IMP package (Stillwell, 1984)

(b) postcode sectors

sector label	beta value	sector label	beta value	sector label	beta value
LS1 2	0.42565	LS16 7	0.33437	LS28 5	0.50175
LS1 3	0.35889	LS16 8	0.34915	LS28 6	0.52797
LS1 4	0.35889	LS16 9	0.74272	LS28 7	0.52047
LS1 5	0.00000	LS17 5	0.38080	LS28 8	0.53184
LS1 6	0.42565	LS17 6	0.30987	LS28 9	0.53856
LS10 1	0.74815	LS17 7	0.53048	LS29 6	0.50470
LS10 2	0.76208	LS17 8	0.43515	LS3 1	0.35889
LS10 3	0.75065	LS17 9	0.60457	LS4 2	0.28774
LS10 4	0.70087	LS18 4	0.46395	LS5 3	0.30098
LS11 0	0.49309	LS18 5	0.46395	LS6 1	0.40345
LS11 5	0.48461	LS19 6	0.55153	LS6 2	0.38501
LS11 6	0.44248	LS19 7	0.53310	LS6 3	0.38646
LS11 7	0.49353	LS2 8	0.35889	LS6 4	0.29389
LS11 8	0.46869	LS2 9	0.35889	LS7 1	0.35889
LS11 9	0.42565	LS20 8	0.50470	LS7 2	0.34078
LS12 1	0.43318	LS20 9	0.50470	LS7 3	0.33196
LS12 2	0.43945	LS21 1	0.74272	LS7 4	0.33291
LS12 3	0.43660	LS21 2	0.74272	LS8 1	0.27160
LS12 4	0.43135	LS21 3	0.74272	LS8 2	0.26756
LS12 5	0.43251	LS22 4	0.61252	LS8 3	0.42318
LS12 6	0.43184	LS22 5	0.61252	LS8 4	0.36523
LS13 1	0.51688	LS23 6	0.61252	LS8 5	0.40159
LS13 2	0.51071	LS23 7	0.61252	LS9 0	0.50568
LS13 3	0.53951	LS24 9	0.61252	LS9 6	0.36936
LS13 4	0.47738	LS25 1	0.47769	LS9 7	0.37365
LS14 1	0.35063	LS25 2	0.47769	LS9 8	0.47195
LS14 2	0.36583	LS25 3	0.48386	LS9 9	0.51260
LS14 3	0.49714	LS25 4	0.48386	BD10 0	0.00000
LS14 5	0.36583	LS25 5	0.48386	BD11 1	0.53837
LS14 6	0.34718	LS25 7	0.48386	BD3 7	0.50175
LS15 0	0.47991	LS26 0	0.71844	BD4 8	0.53856
LS15 4	0.43124	LS26 8	0.61331	WF10 2	0.48386
LS15 7	0.37740	LS26 9	0.51190	WF2 0	0.65828
LS15 8	0.39462	LS27 0	0.62643	WF3 1	0.65828
LS15 9	0.39596	LS27 7	0.54489	WF3 2	0.65828
LS16 5	0.29340	LS27 8	0.62705	WF3 3	0.72238
LS16 6	0.32213	LS27 9	0.55339	WF3 4	0.71714

TABLE 8. Destination selection: the division of movement within and without the small area, postal sectors in Leeds

sector	within	without	sector	within	without	sector	within	without
LS1 2	0.003	0.997	LS1 3	0.001	0.999	LS1 4	0.001	0.999
LS1 5	0.000	0.000	LS1 6	0.001	0.999	LS10 1	0.103	0.897
LS10 2	0.250	0.750	LS10 3	0.185	0.815	LS10 4	0.283	0.717
LS11 0	0.050	0.950	LS11 5	0.042	0.958	LS11 6	0.088	0.912
LS11 7	0.103	0.897	LS11 8	0.079	0.921	LS11 9	0.024	0.976
LS12 1	0.042	0.958	LS12 2	0.046	0.954	LS12 3	0.068	0.932
LS12 4	0.091	0.909	LS12 5	0.076	0.924	LS12 6	0.013	0.987
LS13 1	0.063	0.937	LS13 2	0.134	0.866	LS13 3	0.112	0.888
LS13 4	0.093	0.907	LS14 1	0.052	0.948	LS14 2	0.084	0.916
LS14 3	0.048	0.952	LS14 5	0.083	0.917	LS14 6	0.094	0.906
LS15 0	0.097	0.903	LS15 4	0.056	0.944	LS15 7	0.076	0.924
LS15 8	0.090	0.910	LS15 9	0.012	0.988	LS16 5	0.031	0.969
LS16 6	0.069	0.931	LS16 7	0.095	0.905	LS16 8	0.032	0.968
LS16 9	0.146	0.854	LS17 5	0.046	0.954	LS17 6	0.051	0.949
LS17 7	0.123	0.877	LS17 8	0.092	0.908	LS17 9	0.077	0.923
LS18 4	0.071	0.929	LS18 5	0.092	0.908	LS19 6	0.115	0.885
LS19 7	0.266	0.734	LS2 8	0.003	0.997	LS2 9	0.019	0.981
LS20 8	0.325	0.675	LS20 9	0.163	0.837	LS21 1	0.277	0.723
LS21 2	0.424	0.576	LS21 3	0.314	0.686	LS22 4	0.715	0.285
LS22 5	0.152	0.848	LS23 6	0.546	0.454	LS23 7	0.398	0.602
LS24 9	0.111	0.889	LS25 1	0.128	0.872	LS25 2	0.145	0.855
LS25 3	0.037	0.963	LS25 4	0.132	0.868	LS25 5	0.011	0.989
LS25 7	0.337	0.663	LS26 0	0.220	0.780	LS26 8	0.292	0.708
LS26 9	0.075	0.925	LS27 0	0.225	0.775	LS27 7	0.077	0.923
LS27 8	0.108	0.892	LS27 9	0.109	0.891	LS28 5	0.164	0.836
LS28 6	0.129	0.871	LS28 7	0.122	0.878	LS28 8	0.116	0.884
LS28 9	0.058	0.942	LS29 6	0.014	0.986	LS3 1	0.018	0.982
LS4 2	0.047	0.952	LS5 3	0.043	0.957	LS6 1	0.135	0.865
LS6 2	0.050	0.950	LS6 3	0.076	0.924	LS6 4	0.049	0.951
LS7 1	0.017	0.983	LS7 2	0.040	0.960	LS7 3	0.067	0.933
LS8 1	0.051	0.949	LS8 2	0.048	0.952	LS8 3	0.057	0.943
LS8 4	0.087	0.913	LS8 5	0.058	0.942	LS9 0	0.115	0.885
LS9 6	0.073	0.927	LS9 7	0.083	0.917	LS9 8	0.068	0.932
LS9 9	0.035	0.965	LS7 4	0.042	0.958	BD10 0	0.000	0.000
BD11 1	0.110	0.890	BD3 7	0.029	0.971	BD4 8	0.073	0.927
WF10 2	0.202	0.798	WF2 0	0.034	0.966	WF3 1	0.144	0.856
WF3 2	0.127	0.873	WF3 3	0.167	0.833	WF3 4	0.054	0.946

TABLE 9. Migrant household accounts: the compostion of in-migrant household numbers

An example of Leeds postcode sector LS6 1

Description	code	count
Households migrating within area	a	265
Households out-migrating from area	b	874
Total "wholly moving" households	a + b = c	1139
Total housing unit demolitions	d	22
Total housing units constructions	e	24
Total vacated housing units available to in-migrant households	b - d = f	852
Total in-migrant households	e + f = g	876

source: UPDATE simulation run

FIGURE 1. The structure of the UPDATE simulation system

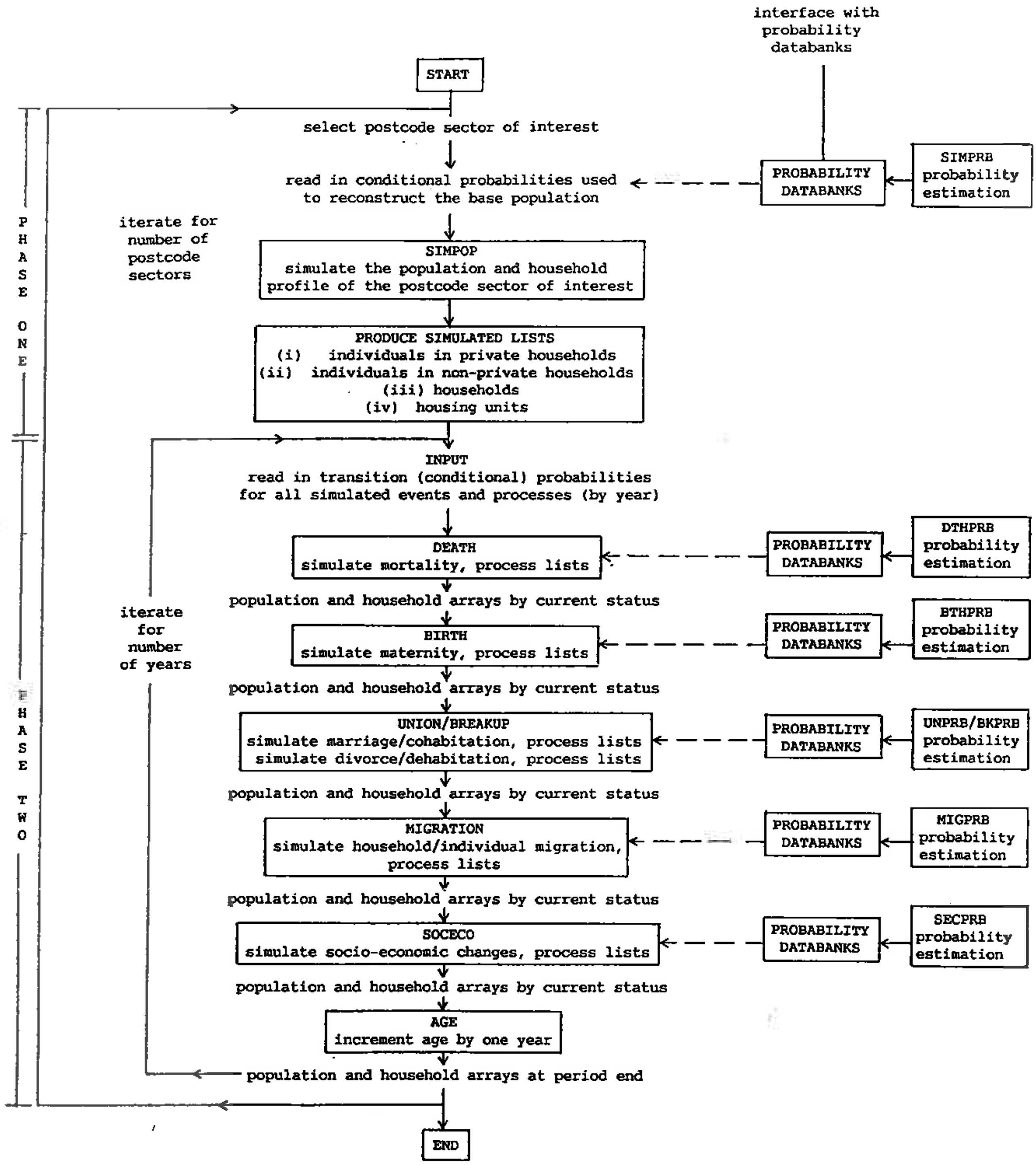

FIGURE 2. Stages in the simulation of marriage and cohabitation

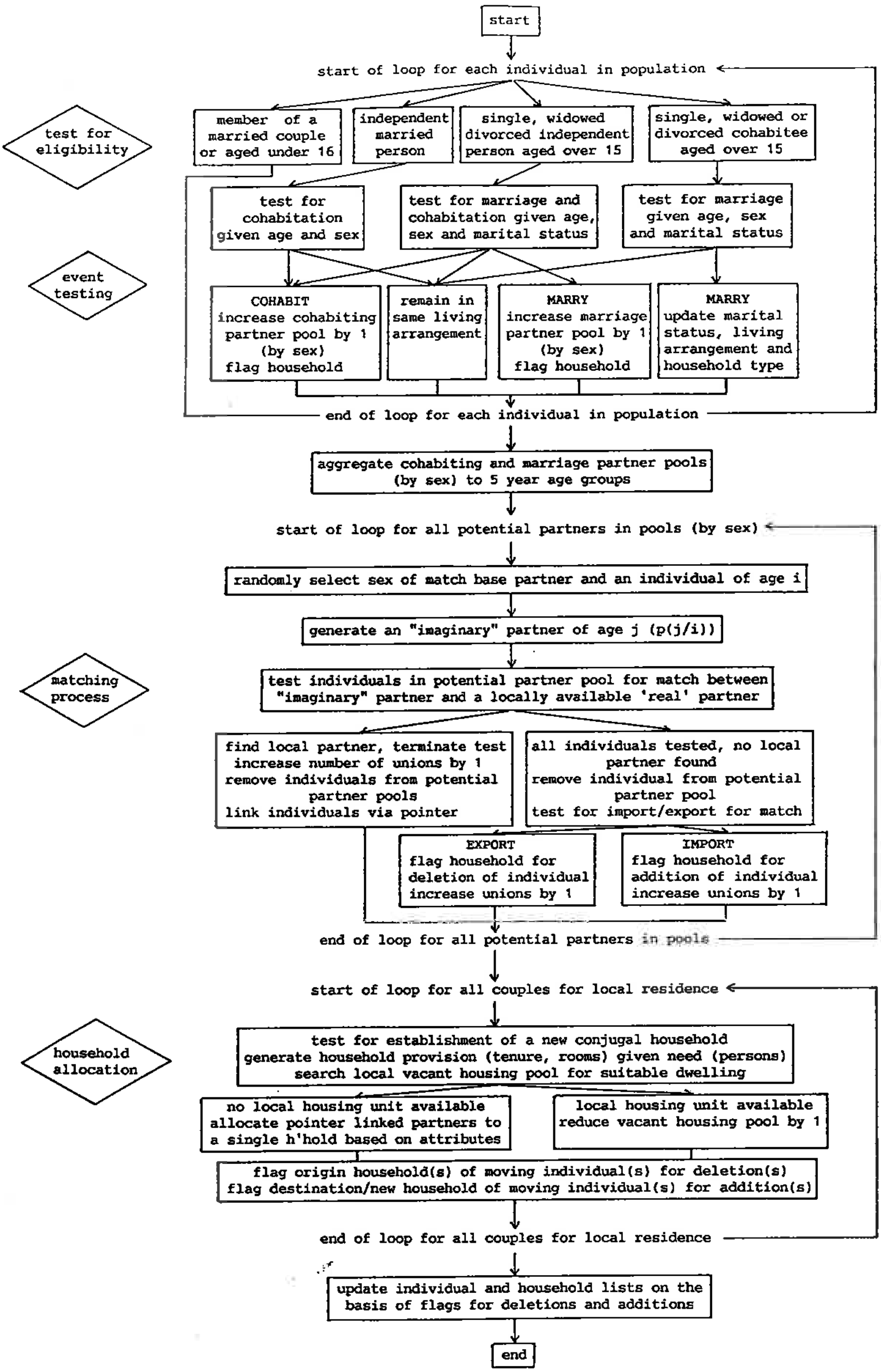

FIGURE 3. Household mobility rates by postcode sector, Leeds 1981

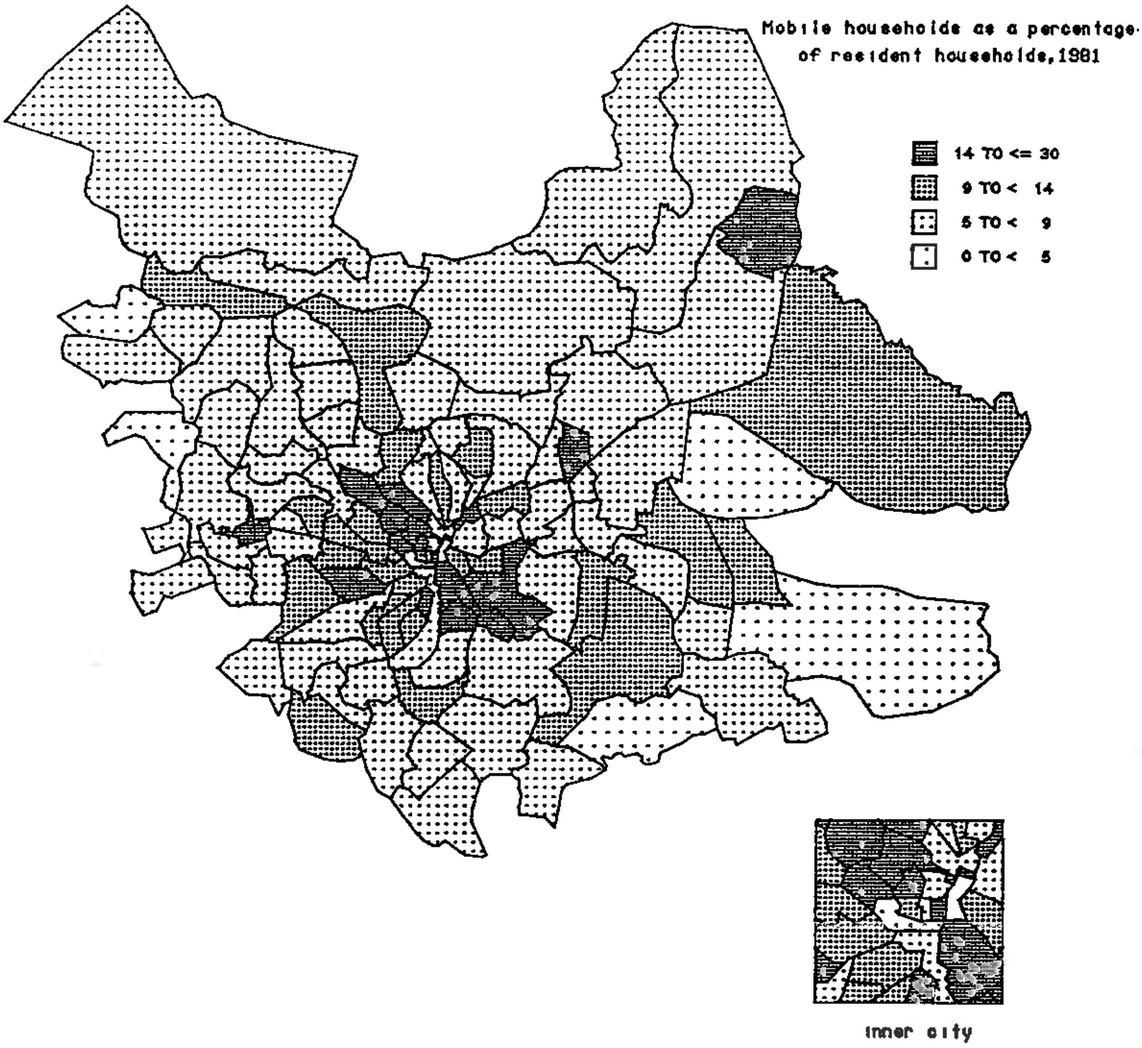

FIGURE 4. Stages in the simulation of within and out-migration of households and individuals

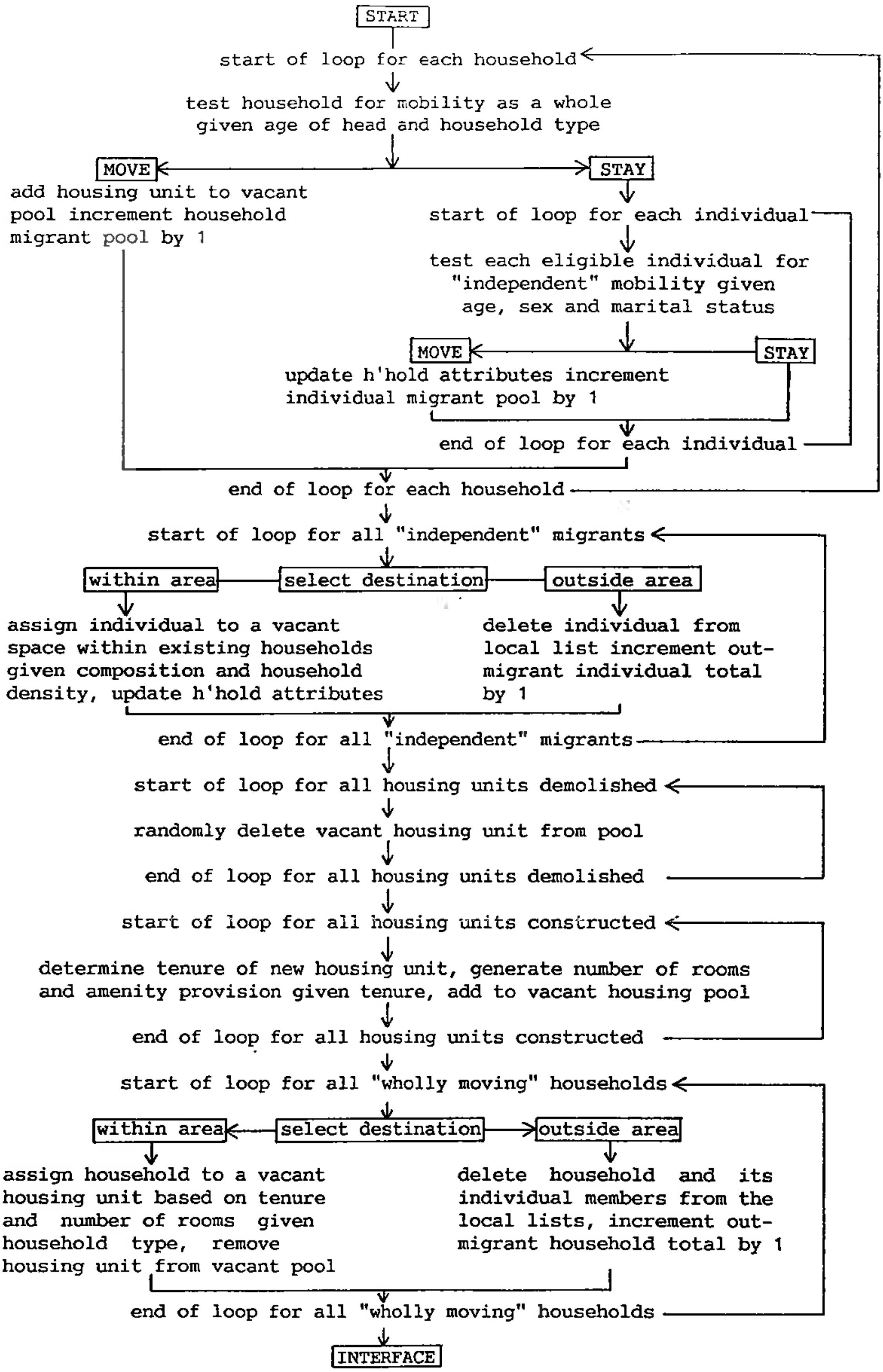

FIGURE 5. Stages in the simulation of in-migration of households and individuals

INTERFACE

determine number of "mobile" in-migrant households
in-migrant households = out-migrant households - housing unit demolitions

compute age of head and household type distribution of "mobile" in-migrant households

start of loop for "mobile" in-migrant households by age of head and type

determine household composition given type

generate remaining attributes of the head of household

generate remaining members of the household (if any) given household composition

assign new household to a vacant housing unit based on tenure and number of rooms given household type

remove housing unit from vacant pool

end of loop for "mobile" in-migrant households by age of head and type

determine number of "housing stock" in-migrant households
in-migrant households = new housing unit constructions

start of loop for "housing stock" in-migrant households

generate household type given tenure and number of rooms

generate age group of head given household type

determine household composition given type

generate remaining attributes of the head of household

generate remaining members of the household (if any) given household composition

end of loop for "housing stock" in-migrant households

compute number of in-migrant individuals by age,sex and marital status given resident population by age, sex and marital status

start of loop for all "independent" in-migrants

assign individual to a vacant space within existing households given household composition and density

update household attributes

end of loop for all "independent" in-migrants

END