Temporal Referencing in a Small-Area Information System: Monitoring Land Annexation in Edmonton, Canada, 1982–1989

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Measurement of multiregional demographic change is presently not supported by a structured conceptual framework other than the traditional cohort survival method. Traditional demography, however, is not suited for the measurement of change in geographic multitudes of small areas, such as neighborhoods or census tracts throughout a city. One of the clearest, albeit not sole, manifestations of this inadequacy is in the case of annexation of exurban land by a municipality. Geographic information systems, on the other hand, seem to constitute overall descriptors for multitudes of small areas, even under conditions of annexation. G.I.S. descriptors, however, do not usually possess a temporal mode. A demographic reference system proposed recently is aimed at providing such temporal mode by measuring change between two census dates in four robust demographic indicators, throughout a contiguous multitude of small areas. By monitoring demographic change throughout the multitude, the reference system constitutes a spatio-temporal mode of measurement. This has a significant meaning for the monitoring of demographic change throughout urban and exurban space, and by further implication, for land-use planning. In a case study, the introduced demographic reference system identifies spatial demographic trends between 1987 and 1989 in Edmonton that seem to echo a municipal annexation of exurban land in 1982.

Demographic considerations relating to territory have been traditionally linked with migration. Integrated considerations of fertility, mortality and migration for a single region had resulted in the cohort component model, while attempts have also been made to apply the same considerations in a multiregional model (Rogers, 1975). These attempts, however, fall short of addressing the demography of multitudes of small area populations such as neighborhoods throughout a city, exurban areas in the urban periphery, or towns and villages throughout a rural region. Demographic change within rural settlements has often been asso-

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ciated with the question of settlement type most likely to benefit from such a change. Within urban subareas demographic change has been associated with geographic and socio-economic mobility patterns (Johansen and Fuguitt, 1984). Both these issues crystalize in the extreme case of exurban land annexation by a municipality with rapidly ageing population. The City of Edmonton, Canada, has been such a case, having annexed its surrounding lands in 1982, and presently experiencing a sharp increase in the population of the aged.

Arguably, traditional demographic methodology cannot contend with municipal subarea growth, with respect to both population growth and, particularly, annexation. The multiregional model in demography, incorporating age specific information on migration, fertility and mortality, has data requirements that, for small populations in particular, are prohibitive. But it is precisely the identification of change patterns in the demography of small populations that is of increasing interest to urban and rural planners (Congdon, 1991). The planning requirements and the available methodology, therefore, are incompatible.

An alternative to the migration-based model of multiregional demography is the consideration of spatial redistribution of population and households (Akkerman, 1985). Recently, this consideration gave rise to a demographic reference system, or a temporal reference system, that measures demographic redistribution over a multitude of small areas (Akkerman, 1992a). The temporal reference system (D.R.S.) is aimed at deliberate imprecise, fuzzy, measurement of change between two census dates throughout a conglomerate of subareas in four demographic indicators. This enables the simultaneous monitoring of demographic change across the whole region, listing the subareas by the value of change in a selected indicator. This measurement, when undertaken for each demographic indicator separately, provides only very limited information. When applied to several such indicators, however, the comprehensive description of the demographic performance of each subarea, albeit imprecise, yields a demographic profile of change for each subarea.

The purpose of this article is to evaluate D.R.S. as an information system for urban and rural planning. This evaluation has two methodological implications. The one is that the introduced reference system can be utilized equally for population as well as for small-area land-use change. The other implication is that D.R.S. inadvertantly turns into a supplementary information system, complementing the spatio-descriptive attributes of G.I.S. The application here will illustrate the particular usefulness of D.R.S. in the measurement of change in a multitude of urban and exurban subareas within a metropolitan region. In the case of Edmonton, D.R.S. will identify a trend where significant shift in the population of the aged occurs from the inner city towards the suburbs. This centrifugal shift seems to echo the annexation of exurban land by Edmonton, in 1982, and the sharp decline in population growth accompanied by a continuing increase in the proportion of the aged within the Edmonton population.

ROBUSTNESS VS. DETAIL IN DEMOGRAPHIC INFORMATION

The use of data in demography relates primarily to measurement of changes occurring over time to age cohorts. Within this demographic notion, usually referred to as cohort component method, the spatial distribution of the population has only been a secondary concern (Keyfitz, 1968).

Attempts in multiregional demography to apply the cohort component model to more than one region had utilized age-specific migration data in the context of multiregional population growth (Rogers, 1975). These attempts, however, left the concern with small populations, significant in both urban and rural planning, largely unanswered.

In order to address the magnitude of the problem it is useful to adopt the multiregional crosstabulation of population by age and region as introduced by the Registrar General of Scotland in 1987. The multiregional tableau has as many rows as there are subareas within the geographic region. It has 18 columns for 18 quinary age groups and a nineteenth column for population totals in each subarea. Each cell of the table, then, identifies the number of persons in a given age group within a specific subarea. This presentation was adopted in two corresponding tables showing the population age distribution in 151 census tracts comprising Edmonton, for 1987 and 1989 (Akkerman, 1992a).

It is fairly obvious that detailed crosstabulations such as those described for Edmonton for 1987 and 1989, preclude a meaningful cohort analysis. Cohort analysis between age groups at different times requires not only equal age and time intervals, but also additional information on mortality, fertility and migration. Although national or even local statistical agencies sometimes collect data that can support these information requirements for relatively small areas, such data are seldom published and access to them is often expensive (Levine, 1988). Even studies on intra-urban migration usually relate to global urban populations (Eaglstein and Weisberg, 1990). Furthermore, data pertaining to census tracts such as the 151 census tracts comprising the area of Edmonton are presented in cells (of a table 18 x 151), the number of people in each cell being so small that any application of demographic rates would be highly questionable. The inadequacy of large-population demography to small-population multitudes, therefore, is the result of excessive detail in the use of age-specific cohort rates.

It is at this point of inquiry where application of fuzzy measures can be an asset when evaluating multiregional demographic growth for small populations. Four relatively easily accessible indicators of multiregional demographic change have recently been used within the context of this inquiry. These were: population, number of households, average household size and mean age (Akkerman, 1992a). Simple fuzzy measures, such as 'decrease', 'stability', and 'increase', are assigned to each of the four indicators throughout the region. Such classification denotes respective changes in the four demographic indicators in each subarea throughout the region, without the commitment of numerical quantities. This measure provides a robust value of change in each of the four indicators for all subareas across a region.

Population and households are the most frequently available data in any census. Mean age and average household size can be easily calculated for each small area when census data are available, and comparison of these two indicators can also easily be undertaken. For brevity, the dynamic change values 'decrease', 'increase' and 'stability' have been denoted as D, I and S, respectively. The orderly consideration of the deliberately imprecise values of demographic change is the essence of D.R.S.

A comparison of data consistently displayed over a multitude of subareas at two census dates invariably shows the trend towards decrease, stability or increase in population and in households, for each subarea. The best illustration for the applicability of this consistent comparison over space and time is in distinctive characteristics displayed by the change within the inner city subareas of Edmonton and its formerly exurban subareas.

URBAN SPRAWL AND THE MEASUREMENT OF CHANGE IN EXURBIA

On January 1, 1982, large agricultural areas surrounding the city of Edmonton were annexed by the municipality, its boundaries being expanded accordingly. As a matter of historic curiosity, the annexation occurred not as a result of the City's initiative, but to some extent, in spite of the City's reluctance to annex. It was mainly the result of the Alberta provincial government's policy to accommodate the perceived rapid population growth of the city, in light of the fact that "vacant land [was] virtually non-existent..." (Associated Engineering Services, 1981). The dilemma, just as in many similar municipal annexation cases, between accommodating increasing numbers of new households, and the added cost of annexing the land was the result of the high expenditures on infrastructure (water, sewer, telephone, power) and soft services (police, fire, schools, public health). The reason for the government's perception of land scarcity can in itself be subject to numerous interpretations. But the Edmonton annexation is at least partly illustrative of the tendency that had lasted well into the eighties, of moving 'back to the countryside'. The result of the annexation was that large numbers of inmigrants in young age groups entered the city. This brought about a decrease in household size and has reversed or slowed down the former trends, which were associated with low oil prices in the eighties. Thus, the administrative annexation of land may aggravate the environmental and socio-economic conflicts over land use in the exurban zone.

Ten years of hindsight since the Edmonton annexation still cannot bring an unambiguous comment regarding its soundness. On the other hand, the fact that the annexation occurred has, more likely than not, affected the spatial distribution of population and households within the city, albeit not necessarily within the annexed areas themselves. Market forces and demographic change must inevitably affect the spatial redistribution of population and households. With urban annexation these forces are likely to be exacerbated. A plain description must be produced in assessing spatio-demographic results of urban policy. Only after such description has been completed can the fundamental questions of land development be successfully addressed.

Hence, in order to properly assess the problems of exurban space, formal tools for the measurement of urbanized development on agricultural land are necessary. These tools must be applied prior to the assessment of any particular change in the layout of urban and exurban space. Such a conceptual tool would be, quite obviously, useful in assessing the extent of success (or failure) in urban policy for sustainable development (Akkerman, 1992b).

It is at this point where D.R.S. can be used precisely as one such tool, although by no means the only one. The advantage of D.R.S. is its formal applicability which, although accepting subjective interpretation of attributes, provides an objective description of change over time. Its relatively narrow range of applicability spans demographic and land-use attributes of small areas, but it does not extend to environmental or socio-economic assessment of an urban area.

SIMPLICITY AND THE DEMOGRAPHIC REFERENCE SYSTEM

D.R.S. is based on the three-value assignment of fuzzy measures to the four indicators. It substitutes the consideration of change in a continuum by considering a qualitative and discrete change at the beginning and end of a period. The qualitative assignment also replaces the separate concerns of fertility, mortality and migration of the cohort survival model (when their measurement is either impossible or impractical) by a summary of demographic performance represented by the change values D, S or I in each of the four demographic indicators.

The demographic performance of a subarea is the subarea's combinatorial state with reference to the three possible values of change in the four indicators, at the beginning and end of a period. Table 1 is a summary showing the actual distribution of observed demographic performance for persons 65+ in Edmonton, based on the comprehensive comparison between 1987 and 1989. Thus, for example, increase in population 65+, combined with lack of growth in number of households, indicates a general decline of a subarea. The demographic performance distribution excludes census tracts that have less than 30 households or those that have less than 10 persons within the subgroup 65+. For a city the size of Edmonton, such census tracts imply nonresidential areas. All other subareas are included in the consideration of period demographic change.

The listing of subareas provided next to each combinatorial state in Table 1 shows all census tracts (by their ordinal numbers) whose demographic performance is specified by the respective combinatorial state. From Table 1 it is easy to identify, for example, all census tracts with growing populations 65+ that have also experienced decline in mean age of persons 65+ between 1987 and 1989.

Beyond the question of a particular combinatorial state of demographic change, a further question to arise concerns the intensity of change in the demographic indicators. The intensity of decrease or increase is given by an integer number calculated on the basis of measurements at both census dates. More generally, this integer relates to the change in quantities at the beginning and at the end of a period. The integer number, reflecting the intensity of change, has been denoted as GRX (as in Growth Index).

If GRX for the period 1987–1989 is 0 the value 'stability' is assigned to the subarea. Both notions of stability and change imply a level of deliberate imprecision in evaluation. The level of robustness in the three qualitative values of demographic change is a matter of convention commonly used in fuzzy sets and referred to as alpha-cut (Dubois and Prade, 1986).

Table 1. Configuration in census tracts for persons 65+, Edmonton, 1987–1989.

P	*H*	*N*	*A*	*Frequency*				*Census Tracts by Ordinal Number*						
d	d	s	s	4		47	73	74	85					
d	d	s	i	2		84	86							
d	s	s	d	5		28	36	42	61	87				
d	i	d	d	1		130								
d	i	s	d	1		48								
s	d	s	s	1		92								
s	d	s	i	1		94								
s	s	s	d	2		62	101							
s	s	s	s	2		33	71							
s	s	s	i	3		32	37	46						
s	i	s	d	1		111								
i	d	d	i	1		80								
i	d	s	i	6		39	72	75	76	100	150			
i	s	s	i	60	3	4	8	9	13	14	15	20	21	30
					31	34	35	41	45	50	51	52	54	55
					56	57	58	60	63	64	65	66	67	68
					69	70	77	78	79	82	83	90	91	93
					95	97	98	102	103	104	106	109	112	115
					116	119	120	121	122	128	131	132	133	149
i	s	i	i	2	49	59								
i	i	d	i	1	136									
i	i	s	s	3	5	53	89							
i	i	s	i	39	2	6	7	10	11	12	16	17	19	22
					23	24	25	26	27	29	88	105	107	110
					113	114	117	118	124	125	126	127	129	134
					135	138	139	140	141	142	144	145	146	
i	i	i	i	1	143									
<10 persons				15	1	18	38	40	43	44	81	96	99	
					108	123	137	147	148	151				

Legend: P - population; H - households; N - mean age; A - average per household; d - decrease; s - stability; i - increase.

A simple formula for calculating GRX has already been introduced (Akkerman, 1992a) but any proposed calculation for GRX is more a matter of convention than a strict rule. It is important, however, that the reasoning behind GRX applies, regardless of whether the total population in each subarea, or only a subgroup of a subarea population is considered. When population subgroups are considered, average household size refers only to the mean number of persons in the selected subgroup, per household, in each subarea. When population subgroups are age groups, mean age refers to the mean age of the persons in the selected age group.

Table 2 ranks the 151 census tracts by the value of GRX calculated for population 65+. For each subarea, accompanying values for households, the mean number of persons 65+ per household, and the mean age of persons 65+, are given. Both Tables 1 and 2, though requiring considerable computing time, are the result of rather simple considerations, outlined earlier. The importance of simplicity in these considerations cannot be overestimated. This is true, in particular, when extending these considerations for an application in the broader context of small-area land-use change.

SMALL-AREA CHANGE IN LAND-USE PLANNING

The implications of the D.R.S. presentation of change in a geographic multitude of small areas go beyond demography. Noteworthy, in particular, are the implications of D.R.S. for land-use planning where the distinction between change in urban, exurban and rural space is of importance within the context of sustainable development. The elements which characterize rural space are varied. They may include demographic-occupational characteristics, as well as land-use ones (e.g., Grossman, 1987). Significantly, D.R.S. exhibits a singular methodology applicable equally to demographic change and to land-use change.

Two analogies can be drawn between demographic change and land-use change within the context of an information system application. First, similar to problems related to data availability in small-area demography, land-use data availability is often very limited or incomplete; in both cases, however, qualitative substitution can lead to comprehensive ranking as a powerful decision-making tool. Second, the quest for understanding change starts at the level of description: only after change has been properly described, can a demographer or land-use planner attempt a causal explanation or prediction.

A referential information system along the lines of D.R.S. assumes imprecision, or incomplete information, as part of its applicability. This is an advantage rather than a deficiency in most practical situations. Land-use classification, moreover, is often not based on quantifiable attributes. A comparison in land-use activity or intensity between two dates, over a multitude of small areas, need not even be reflected in values such as 'decrease', and 'increase'. Normative values such as 'better' and 'worse' can be equally applied in a referential system. Their obvious advantage is that they do not require detailed information of the kind prescribed, for example, by the cohort component model.

Table 2: First thirty and last thirty census tracts ranked by growth index for population 65+, Edmonton, 1987–1989.

			Population 65+						*Population 65+*		
Rank	*C.T.*	*Identifier*	*1987*	*1989*	*GRX*	*Rank*	*C.T.*	*Identifier*	*1987*	*1989*	*GRX*
1	49	CT 023.00	678	1509	55	122	151	CT 140.02	6	6	0
2	140	CT 090.10	85	184	54	123	148	CT 120.01	2	3	0
3	143	CT 090.13	18	39	54	124	147	CT 106.00	5	1	0
4	17	CT 005.03	94	186	49	125	137	CT 090.07	0	0	0
5	136	CT 090.05	73	143	49	126	108	CT 074.00	6	3	0
6	23	CT 006.06	114	215	47	127	99	CT 065.03	0	0	0
7	27	CT 006.10	93	150	38	128	96	CT 064.02	0	0	0
8	25	CT 006.08	64	103	38	129	81	CT 052.01	0	0	0
9	138	CT 090.08	74	119	38	130	44	CT 019.01	0	0	0
10	150	CT 140.01	124	200	38	131	43	CT 018.00	5	7	0
11	7	CT 001.07	111	174	36	132	40	CT 016.01	0	0	0
12	12	CT 002.05	32	50	36	133	38	CT 015.01	0	0	0
13	24	CT 006.07	102	152	33	134	33	CT 011.00	763	752	0
14	142	CT 090.12	50	75	33	135	18	CT 006.01	3	1	0
15	26	CT 006.09	43	63	32	136	1	CT 001.01	0	0	0
16	116	CT 075.08	23	34	32	137	92	CT 061.00	488	481	0
17	59	CT 032.02	849	1227	31	138	71	CT 043.00	783	771	-1
18	80	CT 051.02	9	13	31	139	28	CT 007.07	376	367	-1
19	29	CT 007.02	144	205	30	140	74	CT 046.00	256	250	-1
20	118	CT 075.10	42	60	30	141	84	CT 054.00	828	809	-1
21	6	CT 001.06	47	66	29	142	42	CT 017.00	494	479	-2
22	117	CT 075.09	32	45	29	143	85	CT 055.00	519	503	-2
23	127	CT 078.05	264	366	28	144	47	CT 021.00	660	643	-2
24	133	CT 090.03	87	120	28	145	61	CT 034.00	729	700	-3
25	114	CT 075.06	56	77	27	146	36	CT 013.00	551	527	-4
26	58	CT 032.01	205	281	27	147	86	CT 056.00	460	437	-4
27	136	CT 090.06	29	39	26	148	73	CT 045.00	283	262	-7
28	3	CT 001.03	149	202	26	149	48	CT 022.00	465	423	-9
29	128	CT 078.06	85	114	25	150	87	CT 057.00	516	470	-9
30	9	CT 002.02	168	224	25	151	130	CT 079.00	143	121	-17

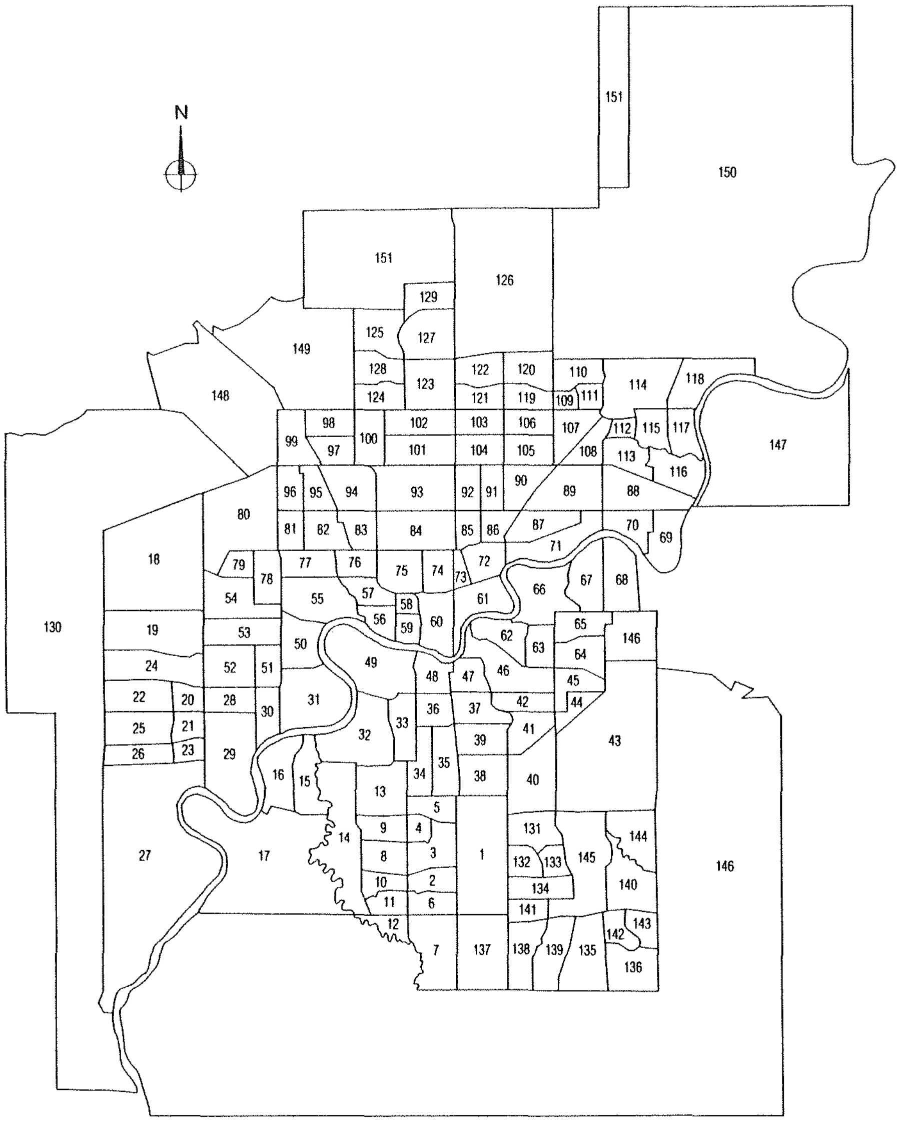
Furthermore, in a referential normative system, subjective assessment can be conveniently substituted in those small-areas in a multitude where only deficient information exists, or where no quantitative information exists at all. Normative application can be further conveniently extended to subjective categorization, such as subjective ranking on a scale, as articulated in fuzzy set-theory (Dubois and Prade, 1986).

Subjective value assignment to small-areas or a more objective calculation procedure such as the one for GRX can both be combined in D.R.S or in a similar system. But the ranking that results from the subjective/objective assignment of small-area values, such as in Table 2, is not only a display of relative intensity values of small-areas. The ranking by demographic or land-use intensities is in itself a decision criterion. In the case of Table 2 it identifies immediately those small-areas within the multitude that have experienced the highest relative increase in the number of senior citizens. An analogy with any land-use attribute is immediate.

Beyond the question of intensity of small-area change in a *single* indicator, there arises the question of the configuration of change in *all* the demographic indicators. The intensity of change in any particular land-use indicator is an important decision-making tool. It does not, however, provide a comprehensive profile of change in each small area. An important implication of D.R.S. to land-use planning is that it presents the changes for *all* the indicators included in the system. Using the three values of change, D, S, I, on four small-area indicators, for example, yields $3^4 = 81$ combinations. Out of these, however, only a fraction actually occurs throughout the multitude. This is due to possible modal relationships between indicators (average households size versus population and households, for example) but it also indicates certain uniqueness in the profile of change that can be useful for analysis and forecasting (Akkerman, 1992a).

Both the intensity and the configuration criteria of D.R.S. are useful in the comparison of niches with distinct attributes (Akkerman, 1992a) or for identifying larger areas with common attributes. It is striking, in this regard, to note the distinction in the configuration of change between 1987 and 1989. Thus, the dynamic forces operating in the urban and suburban areas of Edmonton seem to differ markedly from the one observed in the exurban areas on its periphery, i.e., the zone located outside the pre-1982 annexation city limits. The exurban areas of Edmonton, identified on the map at the fringe of the city (see Fig. 1), are typified by extremely low population densities and arduous access to the city core. Only one such area (census tract 149) falls within the category (I S S I) which is the most common one in terms of the tracts included in it (Table 1). On the other hand, the category that contains the second largest number of census tracts (I I S I) includes also a disproportionately high number of subareas beyond, or adjacent to, the pre-annexation boundary. In these two categories, both the data on population increase for persons 65+ and those for the increase in mean age (also for persons 65+) conform to the well known tendency for older persons to prefer city fringe residence. Thus the increase in the aged population may be attributed to the annexation of 1982. It is, indeed, likely to be a spatio-demographic echo of the 1982 annexation. This interpretation is, in fact, confirmed by an analysis of the market trends which focussed on the spatial distribution of so-called Retirement Villages of Edmonton (Dafoe, 1989).

Figure 1: City of Edmonton census tracts, 1986 (approximate scale 1:135,000).



Furthermore, the exurban areas may be exhibiting traces of polarization that have been observed in some rural areas as a result of influx of non-local residents seeking country homes (Newby, 1979). Table 2 shows that many of Edmonton's exurban census tracts are within the first thirty fastest growing areas (among the 151 census tracts). However, these very same areas of Edmonton have also been associated with very low income (City of Edmonton, 1991). The most likely interpretation is that they contain two different classes, the poor *locals* and the relatively affluent *in-migrants*.

Both Table 1 and Table 2 illustrate the usefulness of D.R.S. in the analysis of spatio-temporal change. The focus of D.R.S. on small-area change constitutes an aspect that is usually not present in geographic information systems. G.I.S. is concerned primarily, if not exclusively, with spatial distribution of land attributes, not with *temporal* features of land attributes. The mode and configuration of change through a multitude of small areas is an important temporal feature that must be taken into account. In this respect, D.R.S. should be seen as a useful complement to G.I.S.

SUMMARY AND CONCLUSION

D.R.S. provides a reference framework for multiregional measurement of demographic change between two dates. D.R.S. ignores the aging aspect of age cohorts, even when a population subgroup is defined by age intervals. Instead, it provides qualitative, albeit imprecise, measures of change (I, S, D) for robust demographic indicators at the beginning and end of a period. D.R.S. thus replaces cohort component measurement by choosing deliberately imprecise measures, yet compensating for imprecision through systematic application of these measures to four different indicators of demographic change (population, households, average household size, mean age). D.R.S. adds an orderly temporal consideration to the notion of geographic information systems which, by and large, concentrate on static representation of spatial configurations. The usefulness of D.R.S. seems to reach beyond demographic concerns. The one immediate and important implication of D.R.S. is the ability for systematic measurement of land-use change in multitudes of small areas, and in the identification of intra-zonal differences, such as the nature of emerging exurban areas. In the case of the city of Edmonton, D.R.S. has identified spatial demographic trends between 1987 and 1989 that seem to echo the impact of the annexation of exurban land in the early 1980s.

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