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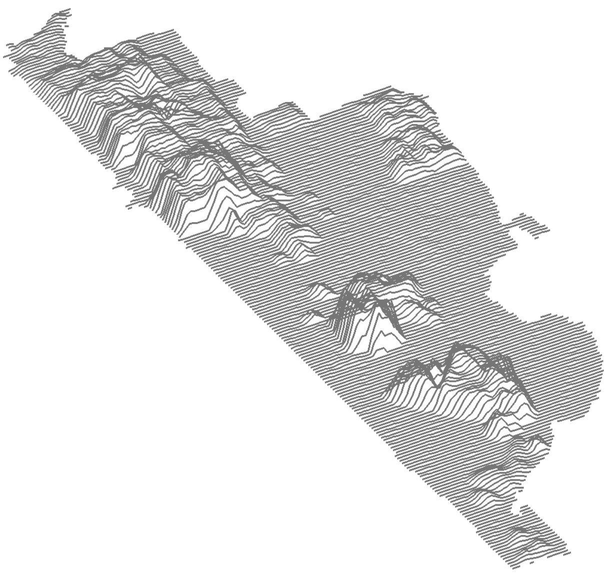
Sustainable Mobility in Cities: Qualitative and Quantitative Analysis

Final Report to the German-Israeli Foundation for the Advancement of Science (G.I.F.)



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1 Introduction

With the rising importance of environmental quality the primary goal of transportation policies is increasingly defined as sustainable mobility. However, the concept of sustainability does not only refer to the natural environment. Transport policies need to accommodate, to varying degrees, three objectives: economic growth, social equity and environmental sustainability. The challenge of policy formulation is complicated by the fact that all three objectives are themselves multi-dimensional. The costs and benefits of policy measures to promote sustainable mobility in cities are likely to be differentially distributed across different segments of the population based on location, socio-demographic and economic characteristics, behavioural patterns (including travel behaviour) and demand attributes. Discrete measures designed to benefit one group often adversely affect others. Spillover effects occur between spatial units and on a temporal dimension. There are positive synergies between some policies, whereas other policies cancel each other out. Thus there is a great societal benefit in designing harmonised, comprehensive policy packages to promote sustainable mobility.

It was therefore the objective of the project 'Sustainable Mobility in Cities' to advance an approach for identifying and recommending policy packages for sustainable mobility. The study was to combine qualitative and quantitative methodological components:

- *Qualitative analysis*. In the qualitative part of the analysis, market segmentation techniques were used to identify groups and locations that will positively or negatively be affected by transport-related policy instruments. The attributes of policy instruments were used to identify complementary and contradictory effects among policy tools. The results were used to suggest possible policy packages, i.e. combinations of policies that are likely to have large positive synergies and little negative side effects.

- *Quantitative analysis*. It was planned that selected policy packages so identified would be submitted to a more rigorous test using a disaggregate travel demand and traffic simulation model incorporating concepts from time-space geography, activity analysis, discrete choice theory, microeconomic consumer choice theory and lifestyle analysis in a Monte Carlo microsimulation framework. The intention was that the mobility patterns generated by the model would be input to environmental submodels forecasting environmental impacts such as energy use, CO_2 emissions, air pollution, traffic noise and land consumption of transport infrastructure in order to allow their assessment in terms of spatial or social equity, and so leading back to the qualitative analysis.

The project was a co-operation between the Department of Geography of the Hebrew University of Jerusalem and the Institute of Spatial Planning of the University of Dortmund.

The project was funded by the German Israeli Foundation for Scientific Research and Development (G.I.F) with a substantially reduced budget, after a proposal for a more comprehensive study on the same topic had been rejected.

Case study city for testing the methodology was to be Netanya, a town with a population of about 150,000 on the Mediterranean shore 25 km north of Tel Aviv.

The project could only partly achieve its objectives:

- The qualitative part of the study was successful in that it established the methodology for identifying groups and locations positively or negatively by transport policies and for qualitatively assessing the effects of policy packages. However, it was not possible to empirically apply the concept to the case study city of Netanya and to define a set of policy packages.

- In the quantitative part, it was possible to establish the spatially disaggregate socio-economic and network databases required for the model. However, of the model development tasks, only the first part, the generation of the 'synthetic population' was completed. The travel simulation model, the core component of the planned model, could not be completed during the project. The consequence was that the link between the travel model and the pre-existing environmental impact submodels could not be established.

The single reason for this failure to complete all planned tasks was that the work programme, even in its modified form after the rejection of the more comprehensive proposal, was far too large for the reduced budget. Hopes by the research teams to exploit synergies with other concurrent research projects did not materialise. That the intended work programme would have required substantially larger resources has since been demonstrated by several similar research efforts both in North America and in Europe.

Nevertheless, within the constraints of the limited budget, significant tangible results have been achieved. They are presented in this report. The report starts with a problem statement and a presentation of the state of the art. Subsequently, the results first of the qualitative part of the study and then of the quantitative modelling work are reported. The report concludes with an outlook on expected future work and first ongoing efforts.

Besides the investigators listed on Page 4, the following individuals contributed to the research: At the Department of Geography of the Hebrew University, Galit Cohen was responsible for the collection of socio-economic and network data of Netanya. At the Institute of Spatial Planning in Dortmund, Franz Fürst and Daria Herbst processed the data for input to the simulation model. Stefan Schönfelder contributed the material for the state of the art in activity-based travel modelling. Klaus Spiekermann provided the methodology for disaggregating spatial data to raster cells. Rolf Moeckel developed the programme for generating the synthetic population. The report was written by Ilan Salomon, Eran Feitelson, Galit Cohen, Rolf Moeckel, Klaus Spiekermann and Michael Wegener.

2 Problem Statement

Effective and reliable transport systems are crucial for the functioning of post-industrial economies, as such economies are based on rapid movement of goods and people in an increasingly complex spatial pattern (Bell and Feitelson, 1991). Yet such systems generate significant negative externalities, such as air pollution, noise vibrations, safety hazards, visual blight, energy consumption and emission of greenhouse gases and loss of open space (OECD, 1988; Small, 1993a; 1993b). The environmental effects of transport are receiving increasing attention in recent years (Barde and Button, 1990;), due in part to the increasing attention given to non-point sources relative to point sources (for which policies are further developed), and the continuing rise in motorisation levels and vehicle-km travelled in all parts of the world (Salomon et al., 1993).

The growing concern over the widespread environmental effects of transport have generated a plethora of responses. These have been documented in a large number of recent studies (Barde and Button, 1990; Himanen et al., 1992; Banister and Button, 1993; Whitelegg, 1993). Yet most of these responses have been limited to a few direct actions.

In recent years, the formulation of transport policies is increasingly concerned with the concept of sustainable mobility (Masser et al., 1992; Nijkamp, 1994). The challenge in structuring policies designed to achieve such a goal (regardless of the exact definition of it) is that transportation systems have to accommodate to varying degrees three major social objectives: economic growth, social equity and environmental sustainability, each of which is multidimensional. That is, the definition of each requires that several variables be considered. The problem of formulating transportation policies is therefore (following Dery, 1984) a 'complex problem' where each measure is likely to ameliorate part of the problem but is also likely to affect other parts of it. Measures designed to mitigate one type of environmental externality are likely to also affect other environmental parameters, as well as to have effects on the efficiency and equity aspects of the transport system. Thus, each of the three main objectives may impose constraints on the degree to which the others can be attained. This requires that the scope of environmental policies be widened so that comprehensive measures addressing the multiple parameters of the issues be formulated and analysed (Oppenheimer, 1995).

The spatial aspect of environmental policy making is particularly intriguing. Emission of pollutants occurring in one area, often by through traffic, affect both local residents and residents of more distant areas, often in different jurisdictions. Thus, the side effects may also take the form of spatial spillover effects, whereby measures mitigate the externalities in one geographical area but have deleterious effects on other areas. Policy packages, rather than single measures are, therefore, needed to address these multiple secondary externalities. Such packages are likely to be much more effective than single measures (Ewing, 1993; Giuliano and Wachs, 1991; Watterson, 1993; Wegener, 1996). The challenge of sustainable mobility can thus be re-interpreted as the challenge to identify the best policy packages that will help to meet the multiple, non-conforming, objectives of transport systems.

One of the more difficult issues in advancing policy packages is the understanding of the interactions between policy tools. Three types of interactions can be delineated. One, conflicting or supportive *direct* effects between policy measure. These take place within a complex system, in which a policy geared to attain one objective is likely to affect other objectives, not always monitored by the policy maker. For example, increasing city centre parking contradicts efforts to curtain traffic congestion in radial arteries. In other cases different policies can support each other. As Wegener (1996) showed with the help simulation models, improved public transport combined with high parking fees and high petrol taxes can reduce vehicle-km driven, and thereby reduce emission. Moreover, policies in non-transport fields can have substantive effects on the transport system, and transport policies can have substantive effects on other fields. These were termed by Dery (1999) 'policies by the way', or 'residual' policies. Examples include tax policies, from whose perspective transport is a residual policy (Cohen, 1998). Finally, there may be spatial and temporal interactions among policies. Both transport and environmental policies vary across space, and have differential effects in terms of the time span within which they are formulated and enacted. Thus, policies enacted at one time can have differential effects over time, and implications for places other than that in which they were enacted. For example, closures of roads to through traffic in one area can effect traffic flows in far-reaching areas.

Formulating policy packages under such circumstances requires that the implications of the different packages be analysed through simulation models. The challenge this study has to address is thus twofold: to advance an approach for combining policies into policy packages and to advance a microsimulation model that can be used to assess the full range of implications of such policy packages. Once both elements are completed, the simulation model can conceptually be used to assist in the formulation of policy packages that will be used to establish strategies for sustainable mobility.

3 State of the Art

The section reviews several fields of theoretical and methodological innovation in transport analysis and modelling. It starts from a reflection on new travel and activity patterns which call for a new kind of integrated policy packages and for new microscopic methods of policy analysis. Microsimulation combined with activity-based travel analysis and spatial disaggregation are the core elements of this new perspective in travel analysis and modelling,

3.1 New Travel and Activity Patterns

Mobility is a basic human activity which is the outcome of the need for access to various activities such as work, personal and household management, and leisure. While the underlying generators of the need for mobility have not changed much during the last centuries, actual travel patterns are very different from days past. Our ability to explain travel behaviour and the necessity to forecast it have seen great developments during the last 25 years.

Travel patterns during the last century have increasingly been dominated by the private automobile. In retrospect, the automobile was a revolutionary technology which facilitated and brought forward profound changes in human spatial behaviour. The 'horseless carriage' technology literally opened new horizons by enabling mobility at higher speeds, comfort and privacy, flexibility and inexpensive travel.

But it was not solely the technology that has altered mobility and accessibility. Social, demographic, economic, and political processes have made the car a major agent of change during the last century. It was not until the second half of the 20th century that the environmental costs of the car were unveiled, and the downside of driving became a factor in the public debate on sustainable development in transport. Eventually, the growing popularity of private cars resulted in multiple negative (as well as positive) effects which called for policy intervention. It became increasingly clear that the private benefits of automobility exceed the social costs of that technology.

Beyond the growth in vehicle fleet size, evident in both developed and developing countries, there is a significant growth in car usage as measured by vehicle-kilometres and person-kilometres travelled. In many European countries, a significant quarter to a third of all households own, or have at their disposal, more than one car. Moreover, the car has assumed several roles in society, beyond that of a vehicle. It has become a source for status and pride, and an extension of the home, as so often seen in advertisements.

Other relevant trends, which warrant an improvement of analysis tools, include various social and technological processes. For example, the growing pluralism within western society calls for a discriminating factor which lies beyond the explanatory power of simple socio-economic attributes. The concept of life style, as described below, offers a basis for discriminating between market segments. Another trend is that of growing potential of using 'e-travel' options as substitutes for physical travel (Salomon, 1985). Forecasting the effects of such options requires tools which go beyond the capacity of traditional aggregate models. Attitudes have been identified as key factors.

For many years, studies of urban transport focused on the journey to work and the key issue was the split between public and private modes. The explanatory factors were mostly economic and demographic variables. The behavioural modelling approach developed since the 1970s, in congruence with many economic analyses, relied mainly on revealed preference approaches. Such methods, however, fell short of providing insights into the growing complexity of travel patterns, such as car sharing, park-and-ride, kiss-and-ride or activity and trip chaining (Adler and Ben-Akiva, 1979).

Ultimately, transport and travel behaviour analyses are oriented to practical ends. However, two routes of development are implicit in research on travel behaviour. The first is oriented to the practice of transport planning and is concerned with questions of policy analysis and forecasting. The second can be characterised as basic research aimed at developing a deeper understanding of human spatial behaviour. A clear example of this often covert dichotomy is the increased interest in variables which are not readily available or measurable.

There is a permanent wide gap between the conceptual models of behaviour and the practical planning tools which have succeeded in operationalising these theoretical advances. Wachs (1996) mentions a thirty-year gap. With the advent of theoretical developments there should be a continuous effort to translate the very latest theoretical notions into practical tools. A number of developments in travel behaviour analysis have introduced both new concepts as well as new methods designed to address the shortcomings of present techniques.

- First, there is growing utilisation of *stated preference* (SP) approaches. These are used mostly in cases where new alternatives are suggested which due to novelty cannot be observed under conventional revealed preference approaches. Another reason for using SP is to economise on data collection efforts.

- Second, *microsimulation* techniques are brought forward to test and forecast the impacts of exogenous trends (e.g., economic, technological, demographic etc.) and the impacts of policy measures. Microsimulation can model the new travel patterns mentioned above.

- Both techniques rely on different data than the commonly used socio-demographic and economic (SDE) attributes. There is a growing interest in *attitudinal data* (McFadden, 2001) as a factor to explain preference and behaviour. Attitudinal data raise some measurement and forecasting problems, nevertheless, their information intensity is high.

- Third, an important assumption was adopted, that the demand for travel is a *derived demand*, emanating from the demand for activities. Hence, rather than focusing on trips, travel behaviour analysis shifted to activity analysis, where travel is assumed to be a cost to be paid as part of the participation in an activity.

- Recently, some caveats about the widely held 'derived demand' assumption were suggested. They are based on the phenomenon of *excess travel* evident in a number of situations in which trips are generated or extended due to a desire to travel. Thus, people may for example travel to a farther shopping centre not because of its quality but because they derive some benefits from the longer trip – travel is found to entail a positive utility and not just a cost (Mokhtarian and Salomon, 2001). To unveil such situations, it is again necessary to dwell, among others, on attitudinal data.

Another type of explanatory factor, employed in this study, is embedded in the concept of *life style***.** In common language, the concept relates to 'the way people live'. This assumes that there is some type of regularity in behaviour. It is argued that in fact people do make very long-term decisions on various aspects of life: involvement in work, household formation, an orientation towards leisure and an adoption of an ideology. These, combined, can be seen as the 'policy' by which an individual lives, subject of course to various constraints.

The concept of life style rests on the assumption that a comprehensive descriptor of an individual is more powerful than a series of SDE variables. The main underlying reason is that while SDE are, in most cases, correlates of behaviour, the concept of life style has a sound theoretical basis (Salomon, 1980; 1983).

Building on the two-tier choice hierarchy presented by Ben-Akiva and Lerman (1985) which distinguishes between long term 'mobility decisions' and short term 'travel decisions', life style is suggested to form a third, upper tier (Bagley and Mokhtarian, 1999). As life style may be seen as a set of long-term preferences, it can be used as a basis for market segmentation. The population is thus segmented not by simple unidimensional SED factors but by a composite variable that reflects preferences or behavioural intentions. These are affecting revealed behaviour, except for situations where constraints are present.

3.2 Policy Packages

Sustainable development in general and sustainable transport strategies in particular are essentially about balancing three meta-goals: economic growth, inter-generation equity and intra-generation equity. Actually, the balancing of these three meta-goals has been at the centre of transport policy debate for over twenty years, though the relative importance of the goals has changed over time (Masser et al., 1992).

The new facet introduced by the concept of sustainability into the transport policy discourse has been the greater emphasis on the need to balance interests across space and between time scales. That is, it is insufficient to strike a balance at one point in time within preset administrative boundaries where the inter-generation concerns are limited to the environment. Rather it is necessary to try and find a balance between the three meta-goals in a multi-generation time frame and in situations where effects cross national and administrative boundaries.

The discussion of sustainable transport has been ongoing at two different levels. At the first level the likely and desired balances between the three meta-goals are discussed. At the second level the policy measures that should be used to achieve the goals are analysed. Yet, the policy measures discussed are most often geared to address a much narrower set of concerns than those identified at the upper level. That is, the policy measures advanced are only rarely discussed in terms of all three meta-goals.

Perhaps one reason for this apparent discrepancy between discussions is that it is obvious that no single policy measure, or even narrow set of measures, is likely to address all three meta-goals, especially if they also need to cut across time and space limitations. The complexity of policy analyses that would have to address all three objectives of sustainable transport, when they are broadly defined, may thus seem indeed daunting.

Moreover, even when policy measures are analysed with respect to a narrower objective, such as reducing CO_2 emissions, it is often concluded that no single measure is sufficient (Barton, 1992, for example). A common conclusion of such studies is that measures have to be combined in order to achieve their stated purpose. However, policy tools are often not complementary. Actually, in many cases policy tools geared toward achieving one meta-goal may contradict another meta-goal. The most widely discussed case of such a contradiction is the construction of bypass roads which facilitate movement and contribute to economic growth but may have detrimental environmental and equity implications. Therefore, the combination of policy measures into policy packages is not a trivial task.

However, to date there are no systematic studies of how can (and should) such policy packages be designed. Most literature on the effectiveness of various policy measures analyse a single measure or a group of similar measures (such as travel demand management tools or economic incentives, usually with in a single setting. But, as Button (1994) noted, there are fundamental differences between places in both the type and relative severity of the various environmental effects of transport and the policy options available. Thus it is not clear that the experience gained in one place is directly transferable to another. Jones et al. (1993) pointed to the fact that in Europe similar problems are often addressed by very different policy measures.

A second lacuna that can be seen from the literature is the relative dearth of studies analysing the actual effects of the different policy tools. Thus, while there is much anecdotal evidence regarding may possible tools, there is often only little critical analysis of the actual potential of each tool. This is evident, for example, in the case of railways (Feitelson, 1994) and in the case of land use planning (Wegener and Fürst, 1999). In the latter case Newman and Kenworthy (1989) have argued that higher densities reduce energy use of the transport system and the consequent emissions. However, Wegener (1996) has shown that energy prices may explain the differences they found between countries. Both Wegener (1996) and Watterson (1993) in separate studies in very different circumstances found that land use controls may have only limited effect on energy use. Similar disagreement can be found regarding the effects of other policy instruments. Thus, there is a need for comprehensive critical analysis of the situations and conditions under which each type of instrument may be effective.

3.3 Microsimulation

The sustainability issue, together with new technological developments and new planning policies, presents new challenges to travel demand modelling. New intermodal travel alternatives such as park-and-ride and kiss-and-ride, new forms of paratransit such as car-sharing, shared taxis or busses on demand and new lifestyles and work patterns such as part-time work, telework and teleshopping cannot be modelled by traditional aggregate four-step travel models. New activity-based travel models addressing these issues require more detailed information on household demographics and employment characteristics. New neighbourhood-scale travel demand management policies to promote the use of public transport, walking and cycling require more detailed information on the precise location of activities. In addition the models need to be able to predict not only the traditional transport effects, such as travel flows and congestion, but also environmental and equity impacts of transport policies, and this requires small area forecasts of emissions from stationary and mobile sources as well as of immissions in terms of exposed population.

Existing travel demand models are too aggregate to respond to these challenges. The typical travel demand model with its four steps trip generation, trip distribution, modal split and capacity restraint model trips but not the activities that give rise to these trips and so are unable to respond to changes in life styles, such as new living, working and leisure patterns. Moreover, most travel demand models get their spatial dimension through a zonal system in which it is assumed that all origins and destinations, such as residences and work places are uniformly distributed throughout a zone. Spatial interaction between zones is established via networks linked only to the centroids of the zones. Zone-based travel demand models do not take account of topological relationships and ignore that socio-economic activities and their environmental impacts are continuous in space.

In particular, zone-based travel demand models lack the spatial resolution necessary to represent environmental phenomena other than energy consumption or CO_2 emissions. To forecast air dispersion, noise propagation and surface and ground water flows requires a much higher spatial resolution. Air distribution models work with raster data of emission sources and topographic features such as elevation and surface characteristics such as green space, built-up area and high-rise buildings. Noise propagation models require spatially disaggregate data on emission sources, topography and sound barriers such as dams, walls or buildings as well as the three-dimensional location of population. This implies that not only the *attributes* of the components of the modelled system are of interest but also their physical *micro location.* These considerations suggest a fundamentally new organisation of travel demand models based on a microscopic view of human activities. The method for this new type of model is *microsimulation*.

Activity-based transport modelling based on principles of time-space geography (Hägerstrand, 1970) originated in the 1980s but has yet failed to replace the mainstream tradition of aggregate transport modelling as represented by conventional four-step transport model paradigm. However, several concurrent developments have contributed to a significant revival of disaggregate activity-based modelling approaches in the 1990s. One development is the availability of larger and more powerful computers that has overcome former barriers to handling large disaggregate data bases. A second, and more important, development is the increased attention paid to environmental aspects of transport due to the growing urgency of the environmental debate and associated legislation in many countries such as the Intermodal Surface Transportation Efficiency Act and the Clean Air Act Amendments in the United States. Environment-oriented transport planning attracts attention to more complex forms of spatial behaviour such as trip-chains, car-sharing and intermodal trips, all of which cannot be represented in traditional trip-based models, and requires the analysis of environmental impacts of transport that cannot be captured by aggregate, zone-based, approaches. Finally, the rise of geographic information systems (GIS) has made more spatially disaggregate transport models at the sub-zone level possible.

Microsimulation was first used in social-science applications by Orcutt *et al*. (1962), yet applications in a spatial context remained occasional experiments without deeper impact, though covering a wide range of phenomena such as spatial diffusion (Hägerstrand, 1968), urban development (Chapin, 1974; Chapin and Weiss, 1968), transport behaviour (Kreibich, 1979), demographic and household dynamics (Clarke et al., 1980; Clarke 1981; Clarke and Holm 1987; Holm et al., 2000) and housing choice (Kain and Apgar, 1985; Wegener, 1985; Mackett, 1990a; 1990b). In recent years microsimulation has found new interest because of its flexibility to model processes that cannot be modelled in the aggregate (Clarke, 1996).

3.4 Activity-Based Travel Modelling

Probably the most advanced area of application of microsimulation in urban models is travel demand modelling. Disaggregate travel demand models aim at a one-to-one reproduction of spatial behaviour by which individuals choose between mobility options in their pursuit of activities during a day (Axhausen and Gärling, 1992; Ben Akiva et al., 1996, Ettema and Timmermans, 1997). Activity-based travel models start from interdependent 'activity programmes' of household members and translate these into home-based 'tours' consisting of one or more trips. This way interdependencies between the mobility of household members and between the trips of a tour can be modelled as well as intermodal trips that cannot be handled in aggregate multimodal travel models. Activity-based travel models do not model peak-hour or all-day travel but disaggregate travel by time of day, which permits the modelling of choice of departure time. There are also disaggregate traffic assignment models based on queuing or cellular automata, e.g. in the TRANSIMS project (Nagel et al., 1998; Barrett et al., 1999), which reproduce the movement of vehicles in the road network with a level of detail not known before.

Disaggregate travel modelling dates back to the 1970s. Kutter (1972) defined identified 38 'behaviourally homogenous groups' defined by age, sex, socio-economic group, car ownership, occupation, number of children, for practical reasons aggregated to nine groups:

- children under 5 years of age
- children 5-15 years of age
- workers with car, male
- workers without car, male
- workers with car, female
- workers without car, female
- house wives with car
- house wives without car
- pensioners

Individuals from these groups were associated with *activity programmes* derived from travel diaries. The travel model consisted of reproducing the activity programmes of all individuals using microsimulation based on probabilities derived from the travel diaries. A typical microsimulation of an activity programme proceeded as follows (the example is taken form the ORIENT model by Sparmann, 1980):

- Select origin zone
- Select population group
- Select activity programme
- Select trip (from previous destination?)
- Select destination (or return to home?)
- Select mode (same mode as previous trip?)
- Store trip
- Another trip?
- Another person?

Similar models were developed by Kreibich (1972) and Poeck and Zumkeller (1976), Jones et al. (1980), Lenntorp (1976), Root and Recker (1983), Kitamura (1984) and Antonisse et al. (1986) and Gunn et al. (1987). Herz (1984) derived activity programmes and time budgets from the 1982 KONTIV travel survey of Germany (see Table 3-1):

Table 3-1. Daily activity programmes and time budgets (Herz, 1984)

Activity chain	Persons without car					Persons with car			
	Young person	Male worker	Female worker	House wife	Retired	Male worker	Female worker	House wife	Retired
h	12.4	11.1	10.9	30.4	33.3	8.2	10.7	19.1	24.4
hwh	1.6	54.6	35.2	1.4	-	31.3	25.5	2.2	1.8
hwhwh	-	1.3	4.4	-	-	4.8	4.1	-	-
hwhsh	-	5.6	6.5	-	-	3.2	5.4	-	-
hwhshlh	-	-	1.5	-	-	-	1.7	-	-
hwhlh	-	3.3	3.6	-	-	7.5	6.0	-	-
hwbwh	-	-	-	-	-	1.4	-	-	-
hwsh	-	1.3	5.0	-	-	1.2	3.7	-	-
hwswh	-	-	1.5	-	-	-	1.7	-	-
hwlh	-	1.5	-	-	1.0	1.6	-	-	-
heh	30.5	-	-	-	-	-	-	-	-
heheh	4.3	-	-	-	-	-	-	-	-
hehsh	3,8	-	-	-	-	-	-	-	-
hehshlh	1,4	-	-	-	-	-	-	-	-
hehlh	16,8	-	-	-	-	-	-	-	-
hehlhlh	2,2	-	-	-	-	-	-	-	-
hsh	2.0	-	3.9	23.5	19.8	1.3	4.4	21.8	14.2
hshwh	-	-	2.9	-	-	-	-	-	-
hshsh	-	-	-	3.7	1.9	-	-	3.8	2.1
hshshlh	-	-	-	1.4	-	-	-	-	-
hshlh	-	-	-	4.4	6.1	-	-	8.0	6.5
hshlhlh	-	-	-	-	-	-	-	1.8	-
hshllh	-	-	-	-	2.2	-	-	-	1.2
hssh	-	-	-	2.3	-	-	-	2.7	1.4
hlh	3.6	2.0	2.1	12.5	12.2	1.6	1.7	7.8	12.2
hlhsh	-	-	-	1.4	1.4	-	-	2.4	2.0
hlhlh	1.3	-	1.5	1.7	-	-	-	1.9	4.1
hlsh	-	-	-	-	-	-	-	1.5	1.4
Other	20.2	20.8	19.5	17.3	23.1	38.5	33.5	27.0	28.7
Total (%)	100	100	100	100	100	100	100	100	100
h Home	1,038	882	959	1,299	1,277	868	980	1,260	1,194
w Work	11	436	356	8	6	375	311	18	18
b Business	-	8	10	-	1	48	11	3	29
e Education	237	3	3	1	-	1	3	2	-
s Shop	12	10	25	43	37	12	22	47	39
l Leisure	68	27	23	37	57	51	46	55	75
Travel	74	74	64	52	62	85	67	55	85
Total (min)	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440

Axhausen (1989) simulated activity chains for modelling the choice of parking distinguishing between primary (mandatory) and secondary activities and mode choice during trip chains constrained by the previous mode (Table 3-2).

Table 3-2. Mode choice constrained be last mode (Axhausen, 1989)

		Next mode				
		Walk	Bicycle	Car driver	Car passenger	Public transport
Last mode	Walk	yes	no	no	yes	yes
	Bicycle	no (yes)	yes	no	no (yes)	no (yes)
	Car driver	no (yes)	no	yes	no (yes)	no (yes)
	Car passenger	yes	no	no	yes	yes
	Public transport	yes	no	no	yes	yes

Entries in brackets indicate mode changes leaving car/bicycle at intermediate stop.

Recent approaches (Stopher et al., 1996; Kitamura et al., 1996; Ben-Akiva et al, 1996, Ben Akiva and Bowman, 1997; Shiftan 1998; Bowman et al., 1998, Gärling et al., 1998, Arentze and Timmermans, 2000) have enriched the concept of activity-based travel modelling by a multitude of concepts and refinements. State-of-the-art activity-based travel models today take account of micro location (raster cell or address), time of day, time and money budgets, intra-household interdependency of mobility decisions, habitual behaviour and learning. The TRANSIMS model (Nagel et al., 1998; Barrett et al., 1999) predicts movements of individual cars and freight vehicles. A regional cellular automata microsimulation (time-based, time interval one second) executes the generated trips on the transport network. Most recent models move from daily to weekly activity patterns (Doherty et al., 2000).

In other developments also longer-term non-travel decisions such as residential or workplace choice are considered in a microscopic perspective. The idea is that by modelling not only transport but all kinds of spatial behaviour in a city it becomes possible to capture the interaction between long-term and short term mobility decisions, i.e. between land use and transport (Salomon et al., 2002). There is a long tradition of simulation models of urban land use and transport, but these have in the past in general been aggregate zone-based models (Wegener, 1994; 1998). Today there are several microsimulation models of urban land use and transport under development in North America: the California Urban Futures (CUF) Model at the University of California at Berkeley (Landis, 1994; Landis and Zhang, 1998a; 1988b; 2000), the Integrated Land Use, Transport and Environment (ILUTE) model at Canadian universities (Miller et al., 1998), the Urban Simulation (UrbanSim) model at the University of Washington, Seattle (Waddell, 2000a; 2000b) and the 'second-generation' model of the Transport and Land Use Model Integration Program (TLUMIP) of the Department of Transportation of the State of Oregon, USA. There are only few similar projects underway in Europe, such as the AMADEUS project in the Netherlands (le Clercq et al., 2000) and the ILUMASS (Integrated Land-Use Modelling and Transportation System Simulation) project in Germany.

3.5 Spatial Disaggregation

Activity-based microsimulation transportation models require the exact spatial location of the modelled activities, i.e. point addresses as input. However, most available data are spatially aggregate. Micro data of households and workplaces, residences and businesses are rarely available, and where they are, their use is restricted for privacy reasons.

However, even where no micro data are available, GIS can be used to generate a synthetic disaggregate spatial micro database which corresponds to all known statistical distributions (Bracken and Martin, 1989, 1995; Martin and Bracken, 1991). To achieve this, raster cells or pixels are used as addresses for the microsimulation (Wegener and Spiekermann, 1996). To spatially disaggregate spatially aggregate data within a spatial unit such as an urban district or a census tract, the land use distribution within that zone is taken into consideration, i.e. it is assumed that there are areas of different density within the zone. The spatial disaggregation of zonal data therefore consists of two steps, the generation of a raster representation of land use and the allocation of the data to raster cells. Figure 3-1 illustrates the two steps for a simple example (Spiekermann and Wegener, 2000). The following steps are performed:

- First, the land use coverage and the coverage containing the zone borders are overlaid to get land use polygons for each zone. Then the polygons are converted to a raster representation by using a point-in-polygon algorithm for the centroids of the raster cells. As a result each cell has two attributes, the land use category and the zone number of its centroid. These cells represent the addresses for the disaggregation of zonal data and the subsequent microsimulation. The cell size to be selected depends on the required spatial resolution of the microsimulation and is limited by the memory and speed of the available computer.

- The next step merges the land use data and zonal activity data such as population or employment. First for each activity to be disaggregated specific weights are assigned to each land use category. Then all cells are attributed with the weights of their land use category. Dividing the weight of a cell by the total of the weights of all cells of the zone gives the probability that this cell will be the address of one element of the zonal activity. Cumulating the weights over the cells of a zone one gets a range of numbers associated with each cell. Using a random number generator for each element of the zonal activity one cell is selected as its address.

The result of this procedure is a raster representation of the distribution of the activity within the zone (see Section 7).

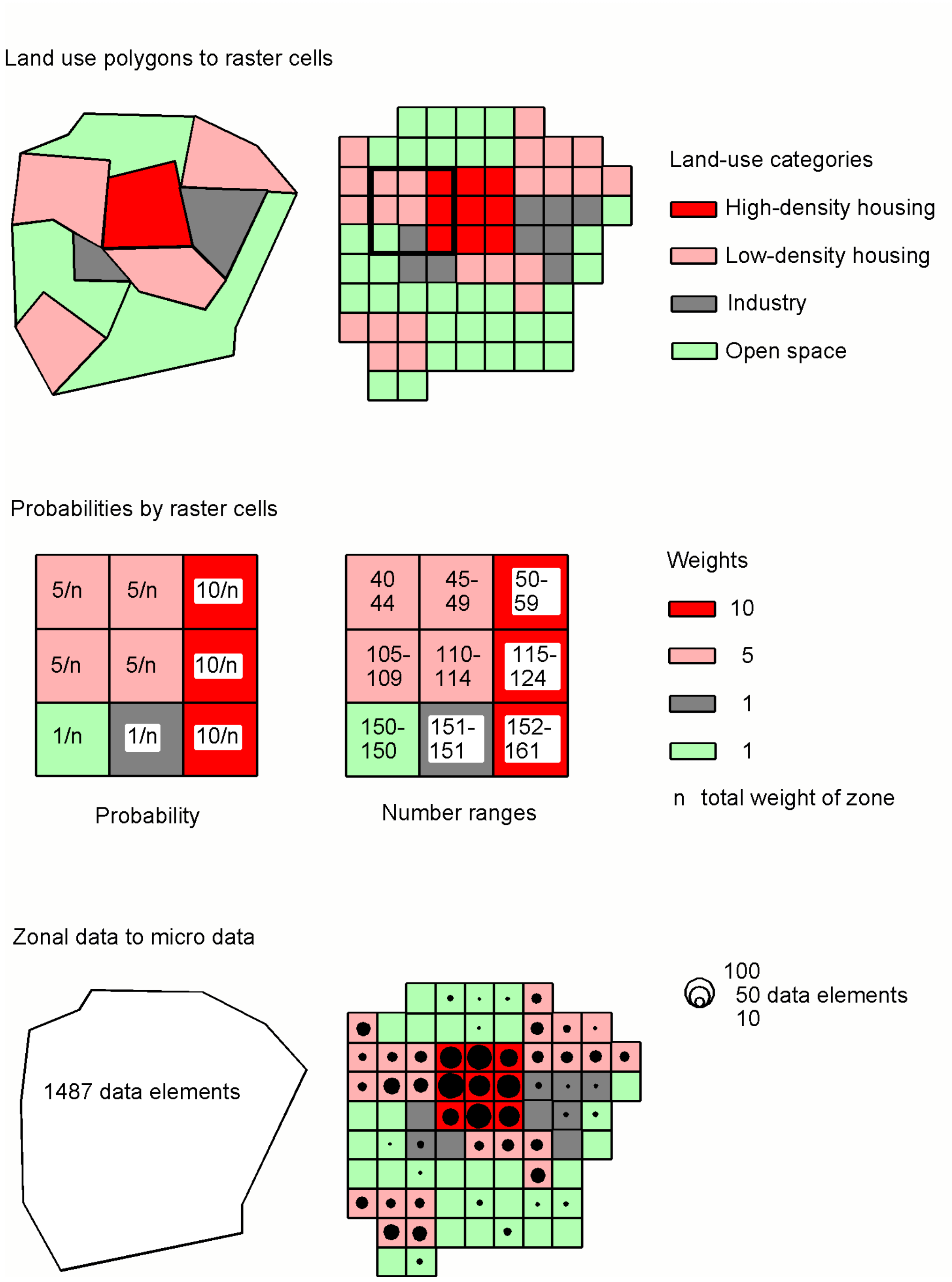


Figure 3-1. Raster disaggregation of zonal data

4. Life Styles

Life style is an empirical concept which attempts to capture the totality of human behaviour. It can be viewed as the sum of activities, distributed in time, space, inter-personal and intra-personal dimensions. It is a physical expression of the pattern of activities which the individuals aspire to engage in, subject to constraints (Salomon, 1980; 1983). Life style may to some extent be correlated with socio-demographic and economic (SDE) attributes, but within a population segment identified by SDE multiple life styles may be exercised.

4.1 Life Styles in Israel

A number of prevailing life styles which are observed in Israel (and in other Western societies) are described below along with the implications for the microsimulation modelling.

- *Workaholics* are people who are committed and devoted to work. Work constitutes for them the main life interest and little time and attention is devoted to other realms of life such as family and leisure. Workaholics are career driven, which implies that they spend a large number of hours doing work. However, this is not necessarily done at the work place. Many workaholics have facilities at home which allow them to work at home in the evening or on weekends. The strong motivation of career advancement also implies that workaholics are willing to have long journeys to work, if their households are located further away from work opportunities. Workaholics are typically upper middle class, white-collar and the phenomenon is independent of age, within the range of working ages. Family status also varies widely. Workaholics generate few, if any, leisure trips, and these are more likely to be on weekends. Their journey to work is likely to be early in the morning, so as to avoid peak period travel. Workaholics can be identified, in principle, either by means of attitudinal attributes (not available in the current study) or by inference from behavioural patterns. This may introduce errors as some people may seem to be work oriented in a given sample day, while there conventional behaviour is different. In the Netanya case, it is suggested to make some general assumption about their share in the population.

- *Yuppies* (Young Urban Professionals) are a breed of people in the upper middle class who's life style can better be exercised in the central city of metropolitan areas and who are less likely to reside in suburban communities. They may be single, cohabitating or married, and in most cases without children. The reason for living in the central city is that it allows much time for leisure activities on a daily basis, immediately after work. Thus cafes, bars, discos etc. are on high demand for these. The trip making behaviour is likely to include significantly less home-bound trips than most other groups, with long days out of home. They are also likely to use private cars, but that is as much related to their income as it is to there life style 'requirements'. Not too many Yuppies are expected to be found in Netanya. There is no simple identification tag.

- *Dinks* (Dual Income No Kids) are households which prefer to delay the expansion of the family, usually until after some career or life style aspirations have been fulfilled. If career objectives are the cause, then these households may be similar to the above-mentioned workaholics, except that here both adult members are work-oriented. Individuals in such households typically have long working days, with one late return trip home. They may be greater consumers of services like restaurants. Dinks who have life style aspirations are likely to be similar in activity patterns to Yuppies, except that they act as a couple rather than singles. Dinks can, in part be identified by demographic factors, but these would disguise such couples who are not Dinks but do not have children yet. It is suggested to make some assumption on the share of all young two-person households.

- *Students* is a status which may include a number of life styles in terms of the observed activity patterns. Students are likely to have diverse activity patterns, as their schedule tends to be irregular, they tend to have longer days which combine studies and leisure, and it will not be atypical for students to leave home in the morning and return home very late at night or even after midnight. Students are easily identifiable by socio-economic data in which occupation is listed.

- *Ideologists-activists* are individuals who contribute time to social or communal activities, usually on a voluntary basis. The main motivation is ideological but it may also be motivated by a desire for out-of-home activities for unemployed individuals. Very often women or pensioners engage in such activities. Communal voluntary activities are mostly done in the afternoon or late morning. Hence such trips are generated off-peak, and are mostly within the neighbourhood. Political activism, on the other hand, generates evening trips, probably not more than once a week and within the city. Identification can only be made by some crude assumption, applied to middle-age households.

- *Family orientation.* Individuals who put the family high on their agenda are likely to spend more time at home and have the home as a base for many of their trips. This means that they return from work as early as possible, and engage in family activities, both within and outside the home. It can be assumed that when very young children are present even the out-of-home trips are likely to be non-motorised and within the neighbourhood, whereas with older children (6-12) trips are likely to be within the city and motorised. One particular point about such households (but not limited to this type) is the growing concern for safety and security of the children. This results in Israel in a growing desire by parents to drive children to their destinations (schools in the morning, other activities in the afternoon or evening). Thus, driving parents (mothers!) are increasingly observed in family oriented households.

- *SYA* (Single Young Adults) include the age group 18-22, when a driver licence is obtained, and mobility is at once enhanced. This sense of independence allows SYA to explore new grounds, not only in the city but also within the whole metropolitan area. SYA are usually still residing at home, and the majority of this group serves in the military, hence its activities are limited to evenings and weekends. Using the household's car, they generate many evening vehicular trips, as in most cases the marginal costs of driving is zero and there seems to be some excitement about it. Identification can be made by age alone.

4.1.1 Ethnic Religious Groups

The population of Netanya is composed of Israeli Jews of various ethnic backgrounds. The major dichotomy is between people of European descent and people of Middle Eastern descent. In the past, this division was well correlated with differences in socio-economic and demographic characteristics. However, as a growing part of the population is Israeli born and a number of additional trends are taking place, this distinction is becoming of lesser relevance, and certainly so for purposes of activity and travel analysis.

A relevant distinction may be made between religious and secular population groups. Netanya has a sizeable group of ultra-orthodox people and many other orthodox people. This parameter indicates some dichotomous differences and some which may be continuous. Religious people who observe all rules, do not travel by motorised transport on the Sabbath, which begins at sunset Friday and ends an hour after sunset on Saturday. On the Sabbath, only walk trips are made, and for relatively short distances. The distinct activity patterns of the Sabbath imply that the weekly activity pattern of orthodox people differs from that of non-orthodox people. Specifically, some activities such as long-distance travel for leisure and social activity is absent. Also, the newly emerging possibility of Saturday shopping in out-of-town shopping facilities is not observed in theses groups. Among the ultra-orthodox, three characteristics are typical: large families, low income and no or low automobile availability.

4.1.2 Demographic Trends

Two major processes of relevance to travel and activity behaviour are taking place. First, the downsizing of households and the growth in their number, and second, the growth in the share of elderly people. As households are units of production, and more importantly, consumption, the growth in the number of households implies more private vehicle ownership and more trips generated. The detailed processes and their implications for microsimulation are described below.

Demographic trends in Israel seem to follow those evident in most western cultures:

- *More and smaller households.* The average household size is declining as a result of a number of independent processes: (i) Decline in the number of children per family. In comparison with the 1960's, when average household size (excluding single-person households) was 4.1 persons, since 1985 the size has stabilised at about 3.85. Most households have fewer children than in earlier periods, but the mean value probably hides the fact that in some groups (particularly the ultra-orthodox), the number of children continues to be high. The implications of the decline in the number of children are that fewer trips for accompanying children are made. (ii) Increase in the number of single person households. Three types of single person households seem to be growing, but their travel impacts may be different. The three sources are: Single by choice, representing a sector of primarily young people who choose to delay the formation of a family or to remain in this status, a growing number of divorcees and a growing number of widows. (iii) Increase in the number of single parent households, as a result of child bearing outside marriage (limited number), divorce and widowhood. The first of these types will typically be a single mother with one child. The latter two types would have any number of children typical for the particular socio-demographic segments, but with one parent missing.

- *Co-Habitation.* Young adults are increasing engaged in co-habitation. Such households usually consist of two persons in their twenties. In terms of household behaviour as a production-consumption system, this type of household is the most diverse. It may be just a sharing of a dwelling unit where the behaviour of the individuals is totally independent of one another, or, at the other extreme, it may be a family type relationship, with full dependence which is not formalised into marriage. However, co-habitation in Israel would usually not include households with children.

4.2 Life Styles in Netanya

In the Netanya model the variation in human spatial behaviour is represented by modelling different life styles. As it was shown, there is a vast and increasing diversity of life styles in the real world. For modelling life styles, concentration on a limited number of dominant life styles is desirable. The identification of dominant, transport-relevant life styles in a concrete spatial and temporal context, e.g. a city, is a complex theoretical and empirical task (including a large-scale empirical survey) that greatly exceeds the resources of the current project. Therefore fictitious life styles based on theoretical considerations and aggregate socio-economic statistics served as substitutes for empirical derived life styles in the project. Another problem to be solved was how to represent life styles in the simulation model. In the social sciences life styles usually are represented in the form of free-form narratives or 'stories'. The story format, though open and potentially rich in content, is not suitable for mathematical modelling. Therefore life styles need to be translated from the open narrative format to some kind of quantitative representation which, however, should preserve as much of the variation in life styles found in reality. Such a representation is the representation of life styles as fuzzy objects.

A 'life style' in the Netanya model is a fuzzy object defined by a set of probabilistic membership functions. A probabilistic membership function is a vector of probabilities specifying the likelihood that individuals with a particular life style belong to a particular category of a set of classified attributes.

The probabilities of the membership functions can be found as observed frequencies in empirical investigations, e.g. household surveys. In the absence of such surveys (as in this project) they are determined by expert judgement and are calibrated, as far as possible, against observed aggregate distributions. The calibration is performed by microsimulation by which a fictitious spatially disaggregated population of individuals and households is generated which, as far as possible, conforms to:

- the membership functions defining each life style,
- aggregate observed distributions such as population by age and sex,
- the observed spatial distribution of land use and activities by zone.

The microsimulation process is able to correct minor mismatches between the membership functions and the observed macro distributions but can be designed to issue warnings where it detects major mismatches.

Netanya was founded in 1928 as an independent resort town, which over the years, with the sprawl of the metro region, has become part of it. Given this biography, Netanya is clearly not the typical suburban community. It consists of a mix of life styles, which to a great extent represents the Israeli urban scene.

To identify the life-style based market segments in Netanya and the proxy variables which indicate membership, a small survey was conducted in which individuals had to identify four life style groups in Netanya, and to provide a short narrative description of the group. Then they were requested to provide a quantitative assessment for one of the life style groups. This pilot study was performed with the co-operation of Israeli students of geography at the Hebrew University.

Some 24 students filled out the questionnaire. In total they provided 58 responses to the question requesting four life-style labels, but these referred to 41 different life styles. This large number indicates that either the respondents had not internalised the concept of life style and actually provided simple SDE variables as the relevant classification basis, or that there are many diverse life style segments in the Israeli (or Netanya) population.

An analysis of the responses suggests, based on an acquaintance with the Israeli society, that in some cases, a single variable is sufficiently powerful to discriminate a group out of the population as a life style segment. For example, being labelled as an ultra-orthodox person provides sufficient information to reveal the life style of that person. This group was mentioned in eight out of 58 responses. However, being labelled as a member of the middle class conveys very little information about the person's or household's life style. Further analysis of the classification provided in this experiment is underway.

Figure 4-1 contains the membership functions needed to define a life style. The membership functions are displayed as empty forms to be completed by experts. To assist experts in completing the forms, background information such as observed age or income distributions should be provided where possible.

Attribute	18-29	30-45	45-60	60+	Total
Age					100

Attribute	None	High school	Training	University	Total
Level of education					100

Attribute	Unemployed	Work	Household	Retired	Total
Labour force participation					100

Attribute	Blue-collar	White-collar	Manager	Self-employed	Total
Occupation (if any)					100

Attribute	1	2	3	4	5	6+	Total
Household size							100

Attribute	1	2	3	4+	Total
Number of workers in household					100

Attribute	Secular	Orthodox	Ultra-orthodox	Total
Religious orientation				100

Attribute	<5K	5-10K	10-15K	>15K	Total
Net household income (NIS)					100

Attribute	Central area	Inner suburbs	Outer suburbs	...	...	Total
Residential location						100

Attribute	Central area	Inner suburbs	Outer suburbs	Total
Workplace location				100

Attribute	Housing	Transport	Other	Total
Use of income				100

Attribute	Work	Education	Leisure	Total
Use of time				100

Attribute	Fixed	Flexible	Irregular	Total
Flexibility of time				100

Attribute	High-rise	Apartment	Terrace	Detached	Total
Housing type					100

Attribute	0	1	2	3+	Total
Number of cars in household					100

Attribute	Culture	Social	Sports	Outdoor	Total
Type of leisure					100

Attribute	City	Mall	Local	Total
Type of shopping				100

Figure 4-1. Definition of life styles

5. Policy Packages

In parallel to the development of the microsimulation model (see Section 6), it was considered which land-use and transport policies should be assessed with a model of this kind. It was clear that because of the potential synergies between policies not only single measures but comprehensive programmes of policies or *policy packages* should be studied.

The first stage in formulating a policy package is to identify the primary goals that it should address. These goals are a function of the way the main problems to be solved are perceived and framed (Dery, 1984).

The problems and goals are stated in general terms, such as to reduce automobile fatalities or to reduce air pollution from traffic. To address these goals they have to be defined in operational terms. To this end targets defined as transport variables have to be specified. In many cases several options for addressing the goals are available. For example, CO_2 emissions can be reduced by reducing the total vehicle-km driven, or by reducing the total energy use per vehicle-km or by reducing the energy use per trip (mainly by shift to a less energy-intensive mode). If the goal is specified quantitatively, such as to reduce CO_2 emissions by a certain percentage, it is necessary to specify the targets in quantitative terms too, and usually to specify the relative contribution to each target chosen.

Table 1 details the possible target variables that can help achieve several general goals. Yet, as it is also shown in Table 5-1, in most cases there are many measures that possibly can assist in achieving the specified target. The question then boils down to which instruments should actually be used under certain circumstances.

The answer to this question is a function of two main considerations: the measures' effectiveness in achieving the targets and their political acceptability. These should therefore be assessed as an input to any further policy packaging step. As in most cases experience within a specific location is limited, this assessment has to rely on experience from elsewhere. To this end a literature review of the actual experience with a wide variety of actions has been undertaken but is not reported here.

One issue not seen in Table 5-1 is the variance in the spatial and temporal scope of the different measures. As discussed elsewhere (Feitelson et al, 2001), measures can be differentiated according to their temporal and spatial dimensions. That is, for each measure the time scale necessary for it to achieve results can be assessed, as well as the spatial scale at which it can be best applied. Thus, a comprehensive policy geared to achieve a specified target should focus on the spatial scale at which the problem is most manifest and be explicit about the time frame in which it is to be addressed.

In a sustainable development framework it is obvious that any policy package should assure that the response is not limited to a temporary relief. Therefore, it is necessary to specify a policy package that addresses the problem in different time frames. Table 5-1 specifies some of the policy measure options as a function of time and spatial level of implementation. Yet, even after such a spatially and temporally differentiated package has been identified, the issues of effectiveness and political feasibility have to be addressed. This is the focus of the framework presented here.

Table 5-1. Goals, targets and possible measures

Goals	Target variables	Possible measures
Reduce noise and vibrations	Reduce noise emissions at source	Electric vehicles Vehicle standards Vehicle testing Quiet pavements Mufflers
	Reduce exposure of residences	Noise barriers Traffic calming Prevent through traffic Land use planning Bypass roads Divert heavy traffic away from sensitive areas
Reduce CO_2 emissions	Reduce total km travelled	Land use planning Gasoline tax
	Reduce energy use per km-vehicle travelled	Vehicle standards Vehicle testing Gasoline tax Electric vehicles
	Reduce energy use per trip (shift modal split)	Vehicle taxes Improve public transport service level (special lanes, better buses, improved rail services) Public transport subsidies Land use planning Bicycle and pedestrian lanes New public transport modes
Reduce air pollution of CO	Reduce emission at source	Catalytic converters Vehicle standards Vehicle maintenance (testing) Electric vehicles Gasoline taxes
	Reduce emission per vehicle-km	Vehicle standards Vehicle maintenance (testing)
	Reduce emission per trip	Improved traffic flows Improved public transport Public transport subsidies
	Reduce exposure	Land use planning Bypass roads
Reduce air pollution of NOx	Reduce emission at source	Electric vehicles Better maintenance (more stringent tests) Induce faster vehicle turnover (through changes in vehicle taxes and registration fees)
	Reduce emissions per trip	Improve public transport Improve rail services Improve cycling (cycling lanes, parking etc.) Land use planning
Reduce air pollution of PM10	Reduce emissions at source	Discourage use of diesel (via taxes)
	Reduce emissions per trip	Land use planning Shift public transport to electric vehicles Improve rail services
Protect open spaces	Reduce transport's footprint on land resources	Reduce road and parking standards Encourage rail transport Land use planning
	Reduce visual blight	Landscaping along transportation routes
	Increase road efficiency	Lower road standards Traffic management measures
Reduce effects on water resources	Reduce discharge induced by transport infrastructure	Reduce parking requirements Use porous asphalt
	Reduce effects on water quality	Require runoff retention and detention elements for all infrastructure projects

5.1 The Scope of Measures

In order to identify the measures' effectiveness and assess their political acceptability it is first necessary to identify their effects. This may seem straightforward. However, in many cases policy failures can be traced to a failure in assessing the full set of possible effects a measure may have.

The effects a measure may have can be analysed at different levels. The most obvious discussion is of their direct effects. These are often the stated goals of the policy they belong to. However, in order to understand the full scope of effects it is also necessary to consider their distributional, behavioural and economic effects. This is especially important in the context of sustainability, as here the tradeoffs between the three meta-goals have to be addressed.

Table 5-2 specifies the general direct, distributional and economic implications of a number of measures, differentiating between technological, traffic management, demand management, and planning measures. The table does not describe the actual effects of the different measures; that has to be done by models and behavioural analyses. In the modelling part of this study such a modelling framework is developed.

However, Table 5-2 shows the range of issues raised by each measure. These are the issues that have to be discussed before the measure is accepted. Yet the acceptability of a measure is not only a function of its effects but also of the context within which it is presented. This context is often considered by transportation professionals as an exogenous variable over which they have little control. However, this is nor entirely true.

While it is undoubted that transportation professionals have only little say over the overall discourse sanctioned by mainstream society, they can effect the way in which a certain policy is presented. In particular, they can present a policy within a wider policy context, e.g. as a part of a more comprehensive policy package.

5.2 A Generic Algorithm for Policy Packaging

The development of policy packages is conceptually shown in Figure 5-1. The first part of the policy packaging algorithm follows the steps described so far. That is, after the initial goals and the subsequent set of targets are specified, the measures that can help to achieve those targets are assessed.

In the first stage these measures are combined into a package that has the potential to address the goals at all relevant time scales. This initial analysis also identifies the spatial level at which the measures can be enacted.

The importance of the spatial discussion is not only academic. Rather, it is one of the factors that determine the authority needed to enact each measure. The implications of the spatial level on the authorisation process needed are a function of the legal and institutional structures.

Table 5-2. Effects of measures

Measure		Direct effect	Affected parties	Economic impacts
Techno-logical measures	Electric vehicles	Reduce emissions at source	2nd and 3rd car buyers	Need battery recharge facilities
	Change in fuels for buses	Reduce emissions at source	Intra-city public transport riders	More expensive buses, fuelling infrastructure
	Improved private car technology	Reduce emissions at source	New car buyers	Lower energy use
	Improved car maintenance	Reduce emissions at source	Car owners and testing facilities	Lower energy use
	Improved road infrastructure	Reduced noise or runoff	Road users	More expensive roads
Traffic management measures	Traffic calming	Reduced through traffic, improved safety in residential areas	Residents and car owners	Minimal
	Co-ordination of public transport services	Increase public transport attractiveness	Public transport users	Improved mobility for car-less
	Park and ride	Increase public transport attractiveness	Public transport and car users – mainly suburban commuters	Improved mobility options; need facilities
	Co-ordination of traffic lights	Reduce stop-and-go traffic	Drivers on main thoroughfares	Improved traffic flows
	Closure of city centre to private vehicles	Reduce emissions and increase PT attractiveness	Employees and visitors to CBD	Increase advantage of suburban centres vis-a-vis CBD
	Pedestrianisation schemes	Encourage non motorised transport	Business customers and visitors to city centres	Change relative advantages between centres
	Truck routes	Reduce exposure (mainly to noise, vibrations and particulates)	Heavy trucks	Reduce truck mobility; restrict location options for large truck users
Demand management measures	Raise gasoline tax	Reduce vehicle-km travelled	All car users (mainly marginal users)	Increase revenue; increase transport costs
	Road pricing	Reduce congestion	Car users in metropolitan areas	Improved efficiency and revenues
	Vehicle taxes	Slow rise in motorisation but higher emissions of older car fleet	Car owners	Revenues, older vehicles on road
	Pollution taxes	Disincentive for high pollution vehicles	Car owners, particularly of older cars	Cost-effectiveness; revenues
	Differential parking fees	Reduce employees commutes by car to CBD thus reducing congestion	Car-owning employees in CBD and hence businesses in CBD	Reduce CBD attractiveness
	Car and van pooling	Reduce emissions per trip	Employees in large employment nodes	Small
	Tax of company cars	Reduce car use	Mid-level and senior employees in large companies	Reduce tax breaks for high income strata
	Administrative controls on vehicle ownership or use	Reduce rise in motorization and car use	Lower middle class	Reduced mobility

Table 5-2 (continued). Effects of measures

Measure		Direct effect	Affected parties	Economic impacts
Infra-structure and land-use measures	Control of urban form	Reduce energy use in transport	middle class - marginal suburbanites	Reduce locational flexibility of businesses and households
	Increase mixed uses	Reduce motorised trips	Urban areas and business parks	Increase locational flexibility
	Cycling paths	Increase use of non-motorised transport	Young, fit people	Marginal
	Bus lanes	Increase bus use	Bus users, drivers	Increase competition over road space at political level
	Light rail	Increase public transport use, save energy	public transport users; employees near rail lines (mainly CBD)	Heavy investments in infrastructure; increase competition over land
	Metro	Increase public transport use; save energy; allow greater densities (reduce loss of open space)	Public transport users in large metropolitan areas	Very heavy investment
	Suburban rail	Increase public transport use, save energy	Suburban areas, long distance commuters	Very heavy investments, encourage long distance suburbanisation
	Noise-sensitive planning	Reduce exposure to noise	Residents in urban areas	Increase housing costs
	Lower standards for roads and parking	Reduce loss of open space and visual blight	Motorists in sensitive areas and drivers	Reduced safety; lower infrastructure costs
	Co-ordination of densities parking and public transport	Encourage use of public transport	Employees near public transport nodes	Encourage development near public transport nodes
	Bypass roads	Reduce exposure in urban areas	Drivers; residents near by passes	Encourage development along by passes

De facto transportation policies in many countries are largely determined 'by the way', using Dery's (1999) term. That is, they are largely a residual of policies enacted by bodies whose primary goals and motives do not concern transportation or environmental issues. Cohen (1998) in a study of the Israeli situation has shown, for example, that tax policies that have important transportation and environmental implications (such as setting gasoline and vehicle taxes) are determined in Israel largely by the Treasury, whose main concern in setting such taxes is fiscal. Thus, the deliberations where these taxes are determined revolve largely about macro-economic considerations. Transportation or environmental considerations hardly effect these discussions. Therefore, the algorithm suggests that the authorisation power and procedures be explicitly recognised. In cases where a certain policy measure is deemed as important within a proposed policy package, but the agency that has the authority to enact it does not see this importance, it is necessary to complement the policy package with a political or public implementation program. Such a program will include the political and public actions needed to get the agency with the authority to act in the way deemed important.

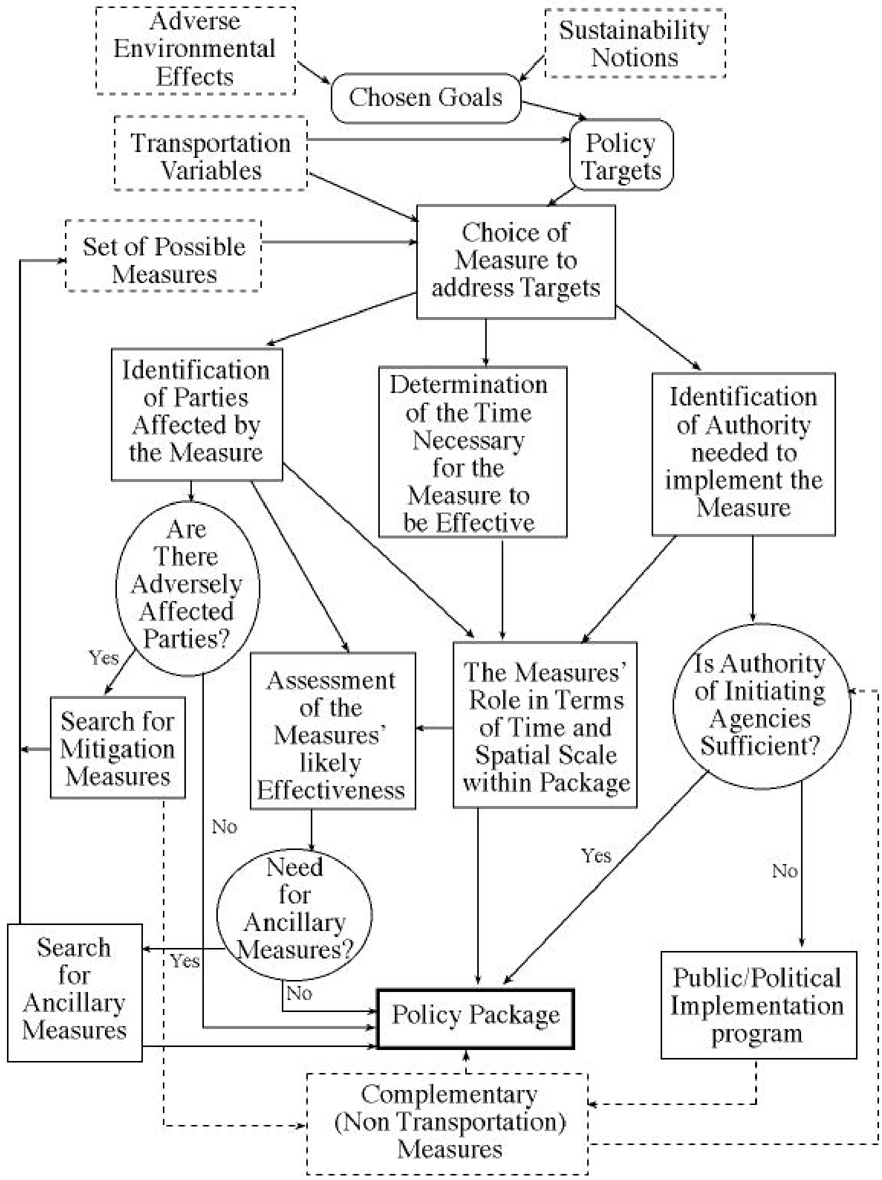


Figure 5-1. A procedure for identifying policy packages

The main political impediment, however, to the enactment of a policy measure is usually not the lack of authority but the perceived distributional and economic implications of the measure. If certain parties see themselves as adversely affected by a measure they are likely to oppose it. Therefore, the main issue that has to be addressed in the policy packaging stage is the distributional effects of the different measures considered.

Table 5-3 describes the general distributional effects of the measures presented in Table 5.2. In essence, a policy package is likely to be more acceptable if, when it is complete, no party is left in a situation where it is adversely affected and no compensation is forthcoming. In other words, one of the major points in packaging measures into a policy package is to assure that all parties adversely affected by the initial set of policies be compensated within the comprehensive package.

Table 5-3. Distributional effects of measures

Measure		Car owners	Car-less	Middle class	Low middle class	Poor	Urban	Rural	Subur-ban
Techno-logical measures	Electric vehicles	-		-			+		
	Change in fuels for buses	+	+				+		
	Improved private car technology						+	+	+
	Improved mainte-nance						+		
	Improved roads	+					+		
Traffic manage-ment measures	Traffic calming	_	_				+		
	Co-ordinated public transport services		+		+	+	+		+
	Park and ride	+					+		+
	Co-ordinated traffic lights	+					+		
	Closure of city centre to private vehicles	-	+				+		-
	Pedestrianisation	-	+				+		
	Truck routes						+		
Demand manage-ment measures	Gasoline tax	-		-	-	--		-	-
	Road pricing	-		-	-	-	-		-
	Vehicle taxes	-		-	--	--		--	--
	Pollution taxes	-		-	--	--			
	Differential parking fees	-			-	-	-		
	Car pooling								
	Company cars tax	-		--					
	Controls on vehicle	-		-	-	-	+		
Infra-structure and land-use measures	Urban form	-	+	-	-	-	+		-
	Mixed-use	+	+						-
	Cycling paths		+				+		
	Bus lanes	-	+		+	+	+		+
	Light rail	-	+		+	+	+		+
	Metro	+	+	+	+	+	+		+
	Suburban rail	+	+	+	+	+	+		+
	Noise-sensitive plan-ning					-	+		
	Lower road and parking standards								
	Density parking and public transport	-	+				+		+
	Bypass roads	+	-	+		-	+	+	-

To do so an iterative process is advanced. Essentially, once an initial package is proposed it should be evaluated according to two criteria. The first is its likely effectiveness. If the initial set is found to be insufficient in terms of meeting the stated targets, ancillary measures can be introduced. These would also be analysed in terms of their distributional effects.

Once an effective policy package is identified, its distributional implications should be assessed. Essentially, the pluses and minuses in Table 5-3 can be summed, even though they clearly are not quantitative. The purpose of this summation is primarily to identify whether there is any party that is on the whole adversely effected to an extent that is likely to raise opposition. A more sophisticated procedure could incorporate a power analysis of the political or disruptive power of the different parties. However, from a sustainable development perspective, where intra-generational equity is one of the meta-goals, it can be argued that power analysis should not be undertaken, as compensation should be offered regardless of disruptive capacity.

If certain parties are identified as being adversely affected to an extent that is seen problematic or unacceptable, additional compensation measures can be introduced. That is, a search for what is termed in Figure 5-1 as mitigation measures would be initiated, where the purpose of these measures would be defined as to mitigate the distributional implications of the prior (effective) policy package. These mitigation measures may have no direct links to the transportation or environmental agenda. For example, if a certain policy package adversely effects the lower middle class, as it focuses on older vehicles making motoring less affordable and reducing this group's mobility, it may be possible to partially compensate them through investments in greater mobility to a wider array of schools or a change in property tax rates that would benefit them. These mitigation measures could then be introduced as part of the policy package.

This procedure does not necessarily need to be neutral from a distribution perspective. It is possible that one of the initial goals would have a distributional facet. In this case, the purpose of the iterative process described here would be to assure that the targeted groups would indeed obtain a net benefit, and that other groups are not adversely effected in a way that would lead them to view the initiative as a zero-sum game where they are on the losing side. That is, also in order to provide a certain group with an advantage it is necessary to compensate other groups to an extent where they will view the comprehensive package as a win-win policy, rather than a zero-sum game.

The outcome of the procedure described in this section has two major ingredients, seen at the bottom of Figure 5-1. The first is a balanced policy package that is both effective in terms of achieving its stated targets and seen as a win-win proposal by all population groups. The second is a public/political implementation program that is construed to create the public pressure needed to move the policy package forward.

Clearly, this algorithm is at this stage very rudimentary. It has to be tried empirically, in conjunction with the model developed in the next section. It is also likely that the economic aspects have to be introduced in a more structured manner. Still, this algorithm may be a step towards a systemic approach for introducing sustainability principles directly and explicitly into discussions of specific policy measures, something that has not been done so far.

6 The Microsimulation Model

The model planned to be used for this study consists of a microanalytic behavioural model of car ownership, destination, mode and route choice of household members based on concepts of time geography, activity analysis and microeconomic consumer choice theory.

6.1 Model Overview

Figure 6-1 presents the major components of the planned model. The diagram distinguishes model input, mode processing and model output:

- *Input*. There are three types of input data: zonal land use data, zonal socio-economic data and transport network data. These data are contained and updated in a geographic information systems (GIS).

- *Processing*. In a first step, the zonal and network data are converted from the GIS to the input required by the model. In the case of household and work places, this implies the disaggregation of zonal one- or two-dimensional distributions of households and workplaces to pseudo micro data, the so-called 'synthetic population' see Section 6.3).

- *Output*. The resulting travel flows by network link and time of day are output for being post-processed by environmental impact submodels yielding indicators of exposure of population to air pollution and traffic noise.

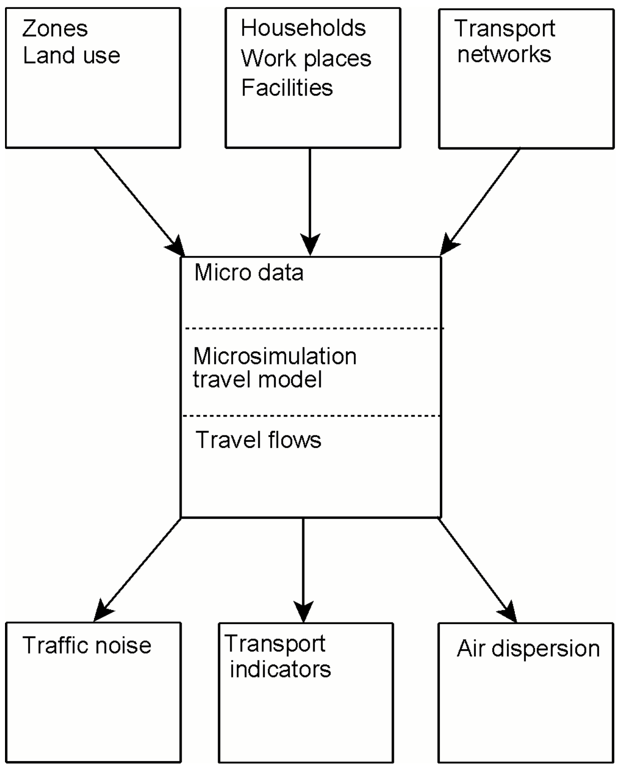


Figure 6-1. The Netanya model: overview

6.2 Travel Behaviour

The travel behaviour microsimulation models for each member of each household the selection of an activity programme (defined as a schedule of tours), car availability and, and, subject to these selections, for each tour a tour departure time and for each trip a trip departure time, destination, mode and route.

Each household is defined by its household attributes, its life style and its residential location, and by the personal attributes of its members. A location in the model is a micro location, i.e. a raster cell.

The destination of a trip is selected by logit choice, where locations of destinations are also micro locations. Generalised costs of travel to the destinations are calculated as a combination of travel time and travel cost of minimum paths of relevant modes walk, cycling, public transport and car (if available) with a random disturbance term added to each link impedance and waiting/transfer time in the public transport network (stochastic minimum paths). For work, school and university trips the destinations are already known.

Mode choice is performed by logit choice based on the generalised costs of stochastic minimum paths; the selected route is the stochastic minimum path. After each trip, the travel times of all traversed road links are updated to account for congestion.

If congestion is encountered during a trip, short-term adjustment resulting in a postponement of the trip or a change of mode or route may occur. In order to facilitate long-term learning, information on the generalised costs of the congested network by time of day of the current simulation period is used in the next period.

One important objective of this approach to traffic microsimulation will be to accomplish realistic assignment of travellers to modes and routes without extensive iteration, as computing requirements of iterative assignment in large urban road networks has proved to be a serious problem in TRANSIMS (Nagel et al., 1998; Barrett et al., 1999).

The microsimulation travel model proceeds as follows (see Figure 6-2):

- *Select household*. In the first step a household is selected for processing from the list of households. The selection has to be spatially random to ensure a non-biased assignment of the network. Each selected household is defined by its household attributes and its associated life style (see Figure 4-1) and by the personal attributes of its members. The household attributes include its residential location. A location in the model is a micro location, i.e. street address, geographical coordinates or a raster cell.

- *Select person*. Next the first household member is selected. For each working person in the household the location of the workplace is known. For school children and university students the location of the school or university is known.

- *Select activity programme*. Depending on the personal attributes of the household member, i.e. age, sex and occupation and workplace, a daily activity pattern is selected from a catalogue of activity patterns. A daily activity pattern is defined as a schedule of tours.

- *Select car ownership and availability*. Depending on household and personal attributes it is determined whether the person has a car at her disposal.

- *Select tour departure time*. The first tour of the activity programme is selected. The departure time is determined as a random variation of the scheduled departure time.

- *Selection of trip departure time*. The first trip of the tour is selected. The departure time is determined as a random variation of the scheduled departure time.

- *Select destination*. The destination of the trip is selected by logit choice. The locations of destinations are micro locations as above. Generalised costs of travel to the destinations are calculated as a combination of travel time and travel cost of stochastic minimum paths (see below) of relevant modes. Relevant modes are walk, cycling, public transport and car (if available, see above). For work, school and university trips the destinations are already known.

- *Select mode*. For the selected destination, mode choice is performed by logit choice based on the generalised costs of stochastic minimum paths (see below).

- *Select route*. For the selected mode the stochastic minimum path is selected as route. The stochastic minimum path is the minimum path with a random disturbance term added to each link impedance and each waiting/transfer time in the public transport network.

- *Move person through network*. Each person travelling through the network is recorded on each traversed link by 10-minute time interval.

- *Update link travel times*. After each trip, the travel times of all traversed road links are updated to account for congestion.

If during a trip a significant amount of congestion occurs, a certain amount of short-term adjustment resulting in a postponement of the trip or a change of mode or route may occur. After each trip the next trip of the route, if any, is selected. After each route, the next route, if any, is selected. After each person, the next person, if any, is selected. After each household, the next household, if any, is selected.

In order to facilitate long-term learning, information on the generalised costs of the congested network by time of day of the current simulation period may be used in the next period.

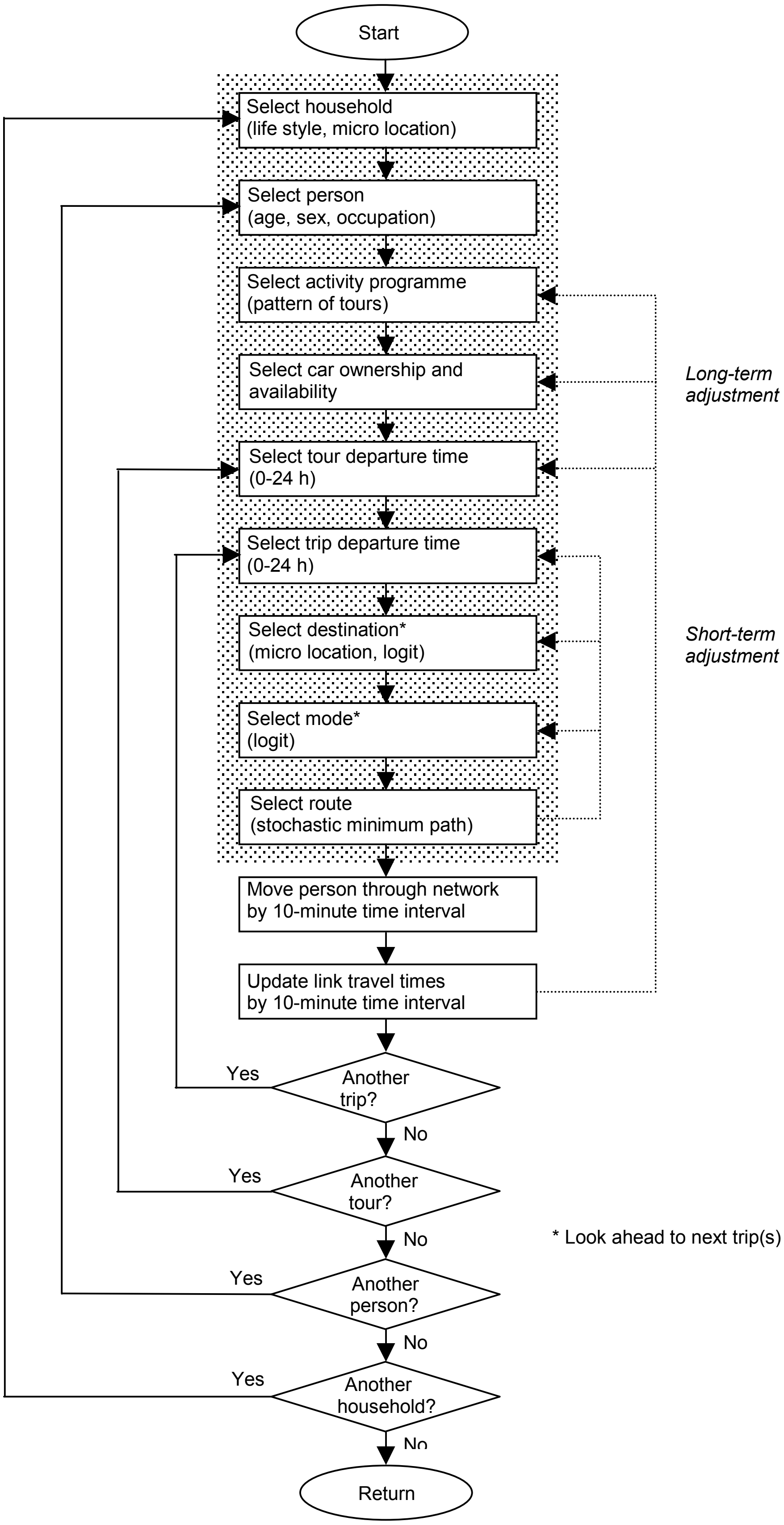


Figure 6-2. Microsimulation travel model (one day)

7 The Netanya Application

7.1 The Study Area

The city of Netanya (population 155,000) is situated at the northern rim of the metropolitan area of Tel Aviv. It was founded in 1928 as an independent resort town, which over the years, with the sprawl of the Tel Aviv metro region, has become part of it. Given this biography, Netanya is clearly not the typical suburban community.

Statistically the city of Netanya is divided into eight regions and 54 zones. The system of zones and regions is shown in Figure 7-1:

Figure 7-1. Map of Netanya with eight regions and 54 zones

7.2 The Database

For the system of zones and regions shown in Figure 7-1, a detailed spatial database was assembled. Whenever available, data referring to zones were used. Other data exist aggregated for the eight regions only. If this information is not available data for the whole city of Netanya were applied. Where data for Netanya were not available, information was estimated using national Israeli or international statistics.

7.2.1 Land Use

The distribution of land use in Netanya was digitised using official City of Netanya maps. The following land use categories were recorded: built-up area, agriculture, public parks and roads. Figure 7-2 presents the distribution of land use in the 54 zones in Netanya.

7.2.2 Transport Network

The existing street network in Netanya with all through traffic and residential streets was digitised from official City of Netanya maps. All city bus lines were coded as sequences of street network nodes ('routes'). In addition, information about the location of bus stops, the frequency of bus services by time of day (morning, noon, afternoon) was collected. For all city, suburban and inter-city bus traffic in Netanya and its suburbs, average speed, total time of service per year, length of line, total time from destination to final stop and distribution of users by line was collected. Figure 7-2 also shows the road network.

7.2.3 Zone/Region/Netanya Data

At the level of the 54 zones in Netanya, the following household and housing data were collected (based on the 1995 Micro Census):

Households
- Total households
- Total population
- Average household size
- Percent households with 1, 2, 3, 4, 5, 6, 7, 8, 9, 10+ persons

Housing
- Total dwellings
- Percent dwellings with 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5+ rooms
- Percent dwellings constructed until 1948, 1954, 1964, 1974, 1984, 1989, 1990+
- Average number of rooms per dwelling

Cars
- Cars
- Cars per household
- Cars per 1,000 population
- Percent households with 0, 1, 2+ cars

Employment
- Employment by occupation

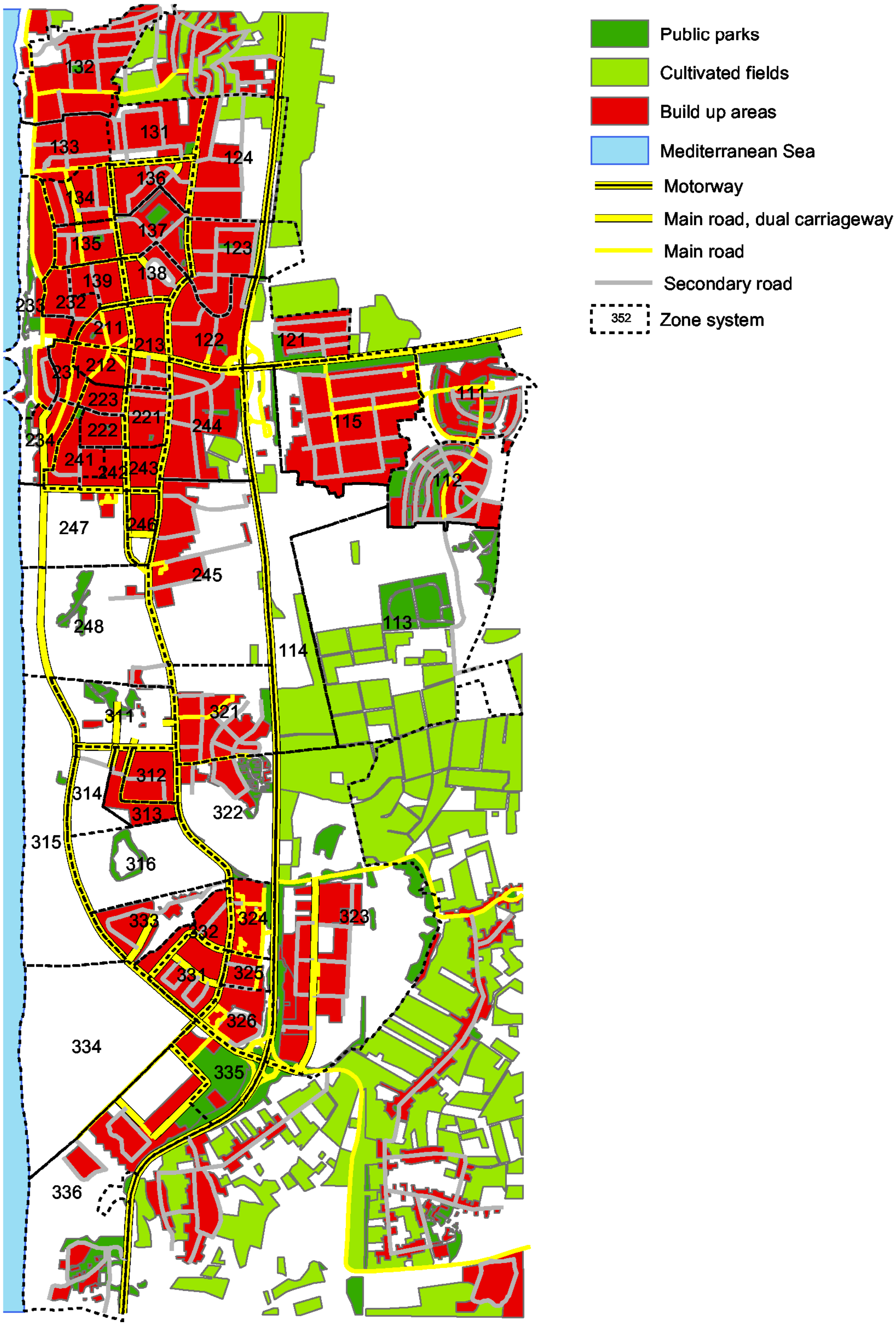


Figure 7-2. Land use and model zones in Netanya

Other data were only available for the eight regions, mostly from the (Survey of Travel Behaviour in Netanya of March 1995. Examples of data available for the eight regions are

- Population by age group (0-7, 8-13, 14-17, 18-29, 30-64, 65+)
- Population by gender
- Cars by ownership (family, business, family business)
- Persons with driving license
- Percent students
- Educational attainment (university, above highschool, highschool/elementary, yeshiva)
- Commuters (to 26 work place locations in Israel)
- Trips by purpose (work, business, shopping, home, study, personal, entertainment, other)
- Trips by mode (motorcycle, car driver, car passenger, bus, taxi, train, other)

Still other data were only available for the city of Netanya as a whole, mostly again from the 1995 Travel Survey. Examples of such data are:

- Population by age (0-4, 5-14, 15-19, 20-24, 25-29, 30-34, 35-44, 45-54, 55-64, 65-74, 75+)
- Percent households in apartment buildings, single-family building
- Trips per capita per day by household size
- Trips per capita per day by number of cars per household
- Trips per capita per day by age and gender
- Trips per capita per day by education
- Total trips by hour of day (0-24 hours) and by purpose
- Trips by parking (free, paid, private)
- Access to bus stop (walk, bus, car) by bus type (city, suburban inter-city)
- Bus passengers by hour of day and bus line and type (city, suburban inter-city)
- Average bus speed by bus line and type (city, suburban inter-city)

Some data could not be obtained for Netanya. These data had to be taken from national statistics of Statistics Israel. Examples of such data are

- the five-year age groups used for selecting the age of the head of household (Table 7-1),
- the probability of type of education as a function of age (Table 7-3),
- the number of earning persons as a function of educational attainment (Table 7-6),
- the distribution of household income (Table 7-7),
- the information on the relationship between education and income (Table 7-8).

In very few cases required data could not be found for Israel. In these cases, similar statistics from international sources were taken as a substitute. Examples are the probability of the age of the first and second child as a function of the age of the mother (Figure 7-14) taken from Möller (1982) or the information on the influence of income on car ownership (Table 7-12) taken from Mogridge (1983) or the information on the differentiation of type of education by gender (Table 7-3) taken from German statistics.

7.3 Spatial Disaggregation

As explained in Section 3.5, the socio-economic data collected for the model zones have to be disaggregated to raster cells for the microsimulation model.

Using the methodology presented in Section 3.5, zonal population and employment in Netanya was disaggregated to raster cells. For this, raster cells of 50 x 50 m size were used. Figure 7-3 shows the 54 zones of Netanya (left) and their disaggregation to raster cells (right). Different grey shades have been assigned randomly to distinguish zones.

Figure 7-3. Zones (left) and 50 x 50 m raster cells (right) in Netanya

The city of Netanya fits into a rectangular area of 89 x 221 raster cells of 50 m x 50 m size or a total of 19,669 raster cells. Each cell is distinguished by x-coordinate (column) and y-coordinate (row) in this 89 x 221 matrix. For each raster cell, the zone to which it belongs and its predominant land-use type are recorded. Figure 7-4 shows the land use polygons of Figure 7-2 disaggregated to raster cells.

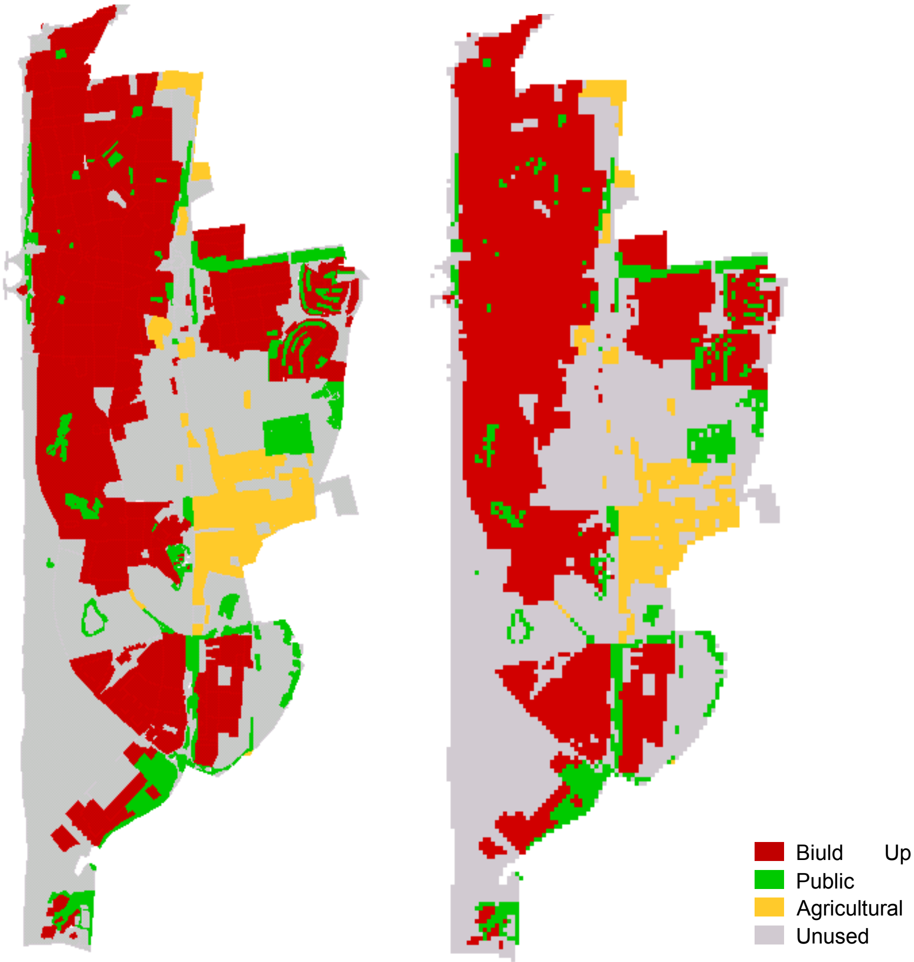


Figure 7-4. Land-use polygons (left) and 50 x 50 m raster cells (right) in Netanya

Since total population is known for every zone in Netanya, persons can be distributed to raster cells depending on the land use of the raster cells in the zone. The data distinguish four land use types: 'built-up area', 'public park', 'agricultural land' and 'unused area'. Each land use type was assigned a probability that persons live on that area. 'Built-up area' gets a value of 250, 'agricultural land' and 'unused area' a value of one, and 'public park' a value of zero. In other words, 99 percent of the population live on 'built-up area', and less than one percent live either on 'agricultural land' or 'unused area'. Given these probabilities the distribution of persons is done by Monte-Carlo-Simulation.

Figures 7-5 and 7-6 show population and employment in Netanya in three-dimensional form. Figure 7-5 shows the spatial distribution of residences. One can see the high-density neighbourhoods of the inner city and the neighbourhoods with somewhat lower densities in the outer areas in which there are also a few high-rise housing areas. Figure 7-6 shows the locations of work places. Compared with residences work places are much less concentrated. Highest densities can be found in some industrial estates outside the inner city.

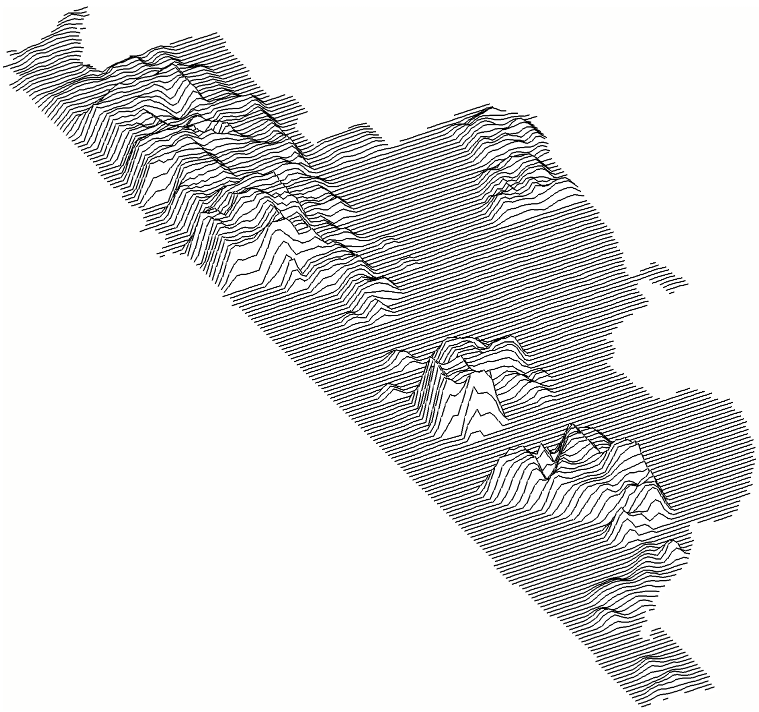


Figure 7-5. 3D raster representation of residences in Netanya

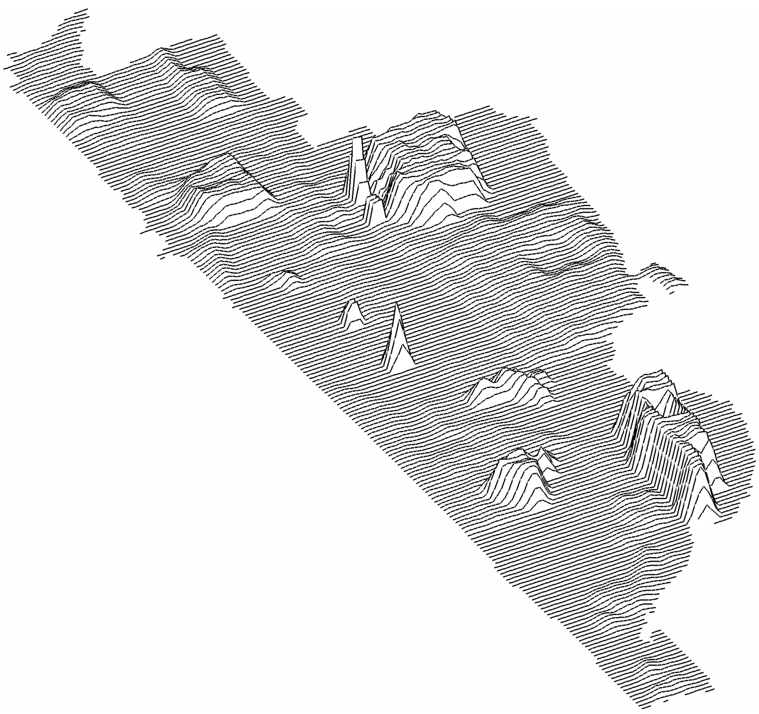


Figure 7-6. 3D raster representation of work places in Netanya

7.4 Synthetic Population

As there is no comprehensive micro database describing all persons with all features relevant for the microsimulation of travel behaviour available for Netanya, it is necessary to simulate a synthetic population as the basis for the microsimulation of travel flows. The aim is to generate a numerical representation of population that is as realistic as possible, i.e. the synthetic population is designed to be statistically equivalent to the actual population.

The simulated population consists of households with different features like address, household size, income, or car ownership. In addition, different characteristics, such as the age and gender of the household members, their religion, their education and their work place are simulated. Since these persons exist only artificially in computer files, this population is called synthetic.

After completion of synthetic population, the generated people will 'travel' in the equally artificial environment created on the computer. In this way travel demand is forecast as a function of the socio-economic and demographic structure of the population. Because each household has an address, the effects of spatially disaggregate environmental impacts on individual households can be simulated. This section deals with the creation of the synthetic population.

7.4.1 Methodology

Typically published tables from censuses or population registers contain information on households or persons in the form of one- or two-dimensional tables of attributes, in which each table cell represents the number of households or persons with a certain attribute or combination of attributes. Moreover, in most cases the rows and columns of the tables represent ranges of attributes, or classes.

If a population of households and persons with a distinct combination of attributes is to be generated from such one- or two-dimensional distributions, certain assumptions about interdependencies between attributes must be made. Based on these assumptions, a distribution of households and persons, which complies with the given one- or two-dimensional distributions can be generated using Monte Carlo sampling, or microsimulation. It is important to note that this is not behavioural microsimulation as in the microsimulation travel model.

In Monte Carlo sampling, every feature is simulated randomly based on the given one- or two-dimensional distribution as constraint. Through the assumptions about interdependencies between attributes, the results become realistic. For instance, most children will live in a family with at least two adults or most seniors will either live with another elder person or with their family as grandfather/grandmother, or alone. Some exceptions will be possible, too.

There are two possible ways to sample a feature: One method is to *draw with replacement*. In this case the probability for one feature always remains the same, e.g. the probability for a household to be ultra-orthodox always will be, say, ten percent – each time a household is simulated, the probability of becoming an ultra-orthodox household is one to ten. The other method is to *draw without replacement*. If, for example, it is known that there are two ultra-orthodox households and 18 non ultra-orthodox households, if an ultra-orthodox household has been selected, there is only one ultra-orthodox household left, and the probability for selecting an ultra-orthodox household should be adjusted accordingly. This is accomplished by drawing without replacement. It guarantees that at the end of the simulation exactly two of the 20 households are ultra-orthodox. In the first case there could be 12 % or 8 %. For this reason, whenever possible, drawing without replacement is applied. Figure 7-7 illustrates the two methods.

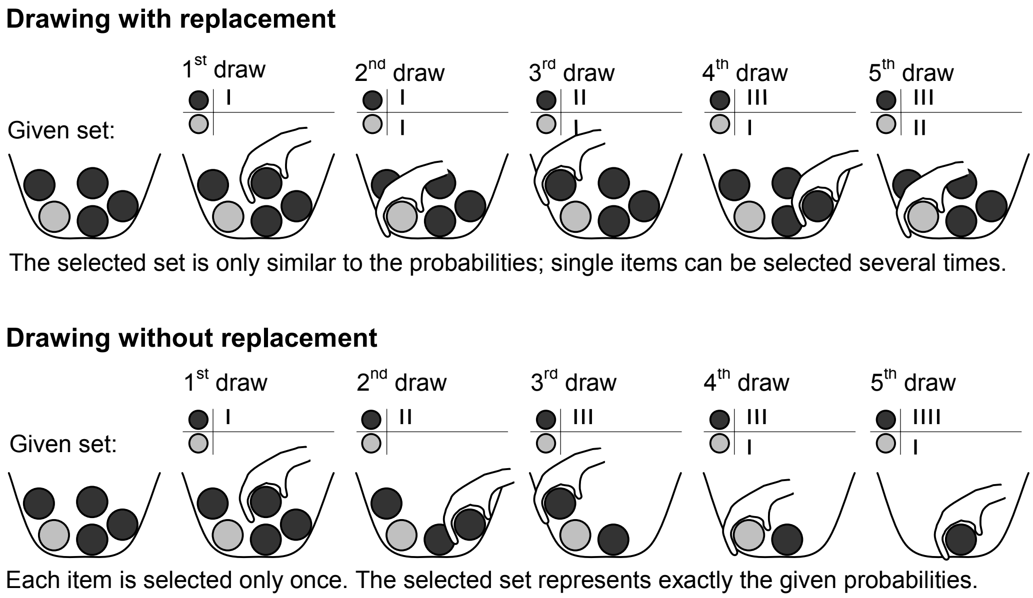


Figure 7-7. The way of drawing can lead to different results

It is tried to create households and persons in a 'natural order'. This means that the features of persons and households are sampled in that order they usually influence each other. First, the head of household with her age, gender and religion is selected. Depending on this information the education of the head of household is selected. On the basis of this information, the size of the household is determined, then depending on all that information the address for this household, and so on. Because every step of the sampling refers to the already selected features, the result becomes more realistic.

There are some cases where a 'natural order' cannot be determined. For instance, on the one hand the number of workers in a household influences how many cars the household can afford. But on the other hand the number of cars might influence the number of workers, since more jobs might be accessible by car. In such cases it is assessed which feature is likely to have the stronger impact on the other. In the example given, it was assumed that the influence of the number of workers on the number of cars is stronger than vice versa.

There are some improbable constellations. As the size of a household depends on the age of the head of household, an eight-person household headed by a 20-year-old person is very unlikely. Wherever possible, such cases are excluded. But a small number of exceptions should be possible. There are some exceptional cases where, e.g., the father left the household and the oldest son takes over as head of household. But generally these constellations are avoided.

7.4.2 The Synthetic Population Generator Programme

Figure 7-8 shows the main structure of the synthetic population generator programme. The programme creates for each zone the required number of household. To create a household, first the head of household is selected. This is useful because many features of a household depend on the characteristics of the head of household. For instance, if the head of household is a younger person or a pensioner, the household is likely to be smaller, if the head of household is aged between 30 and 60 years, there is a good chance that the household is a family.

Age, gender, religion and education of the head of household are selected together. Depending on this information, the household size is determined. If a one-person-household is selected, no more persons need to be created for that household. If a multiple-person household is drawn, the other household members are selected in turn until all persons for the household are selected. Then the housing location in the zone, is chosen. Next the number of earning people and then the income are selected. Depending on all this information, the number of cars is determined. Finally a workplace is assigned to each working person. The programme continues to create households until all households of the zone are created.

Age and Gender

Age is selected by drawing without replacement. By this it is guaranteed that the age distribution of the household members exactly corresponds to the given age distribution of the population. Age and the gender are selected on the basis of a 20 x 2 matrix of 5-year male and female age groups. To select an age and gender, one of these 40 fields is selected, where the probability of selection is proportional to the number of persons in the matrix. Next a random number between 0 and 4 is selected and added to the initial year of the selected age group to determine the exact age. As there are no 5-year age group data for Netanya, data for Israel were used. If a zone had 1,000 people the distribution would be as in Table 7-1. This table is used to determine the amount of persons in every age group for all 54 zones in Netanya.

Table 7-1. Number of persons of each age group and gender in Israel in 1998

	Age																			
	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
m	52	49	48	45	44	37	32	31	30	29	21	16	15	14	12	8	5	3	1	0
f	50	47	45	43	43	37	33	32	32	31	22	18	18	17	16	10	7	4	2	1

Total: 1,000 persons. Source: Central Bureau of Statistic of Israel (1999)

The first person of a household may not be younger than 18 years. Furthermore it is more probable to select a head of household aged 40 than a head of household aged 20. For this reason the following weighting factors have been created. Each value of Table 7-1 is multiplied with the corresponding weighting factor of Table 7-2. In this way children are excluded and it will be much more probable to select a person aged 40 years as head of household than a 20-year old person.

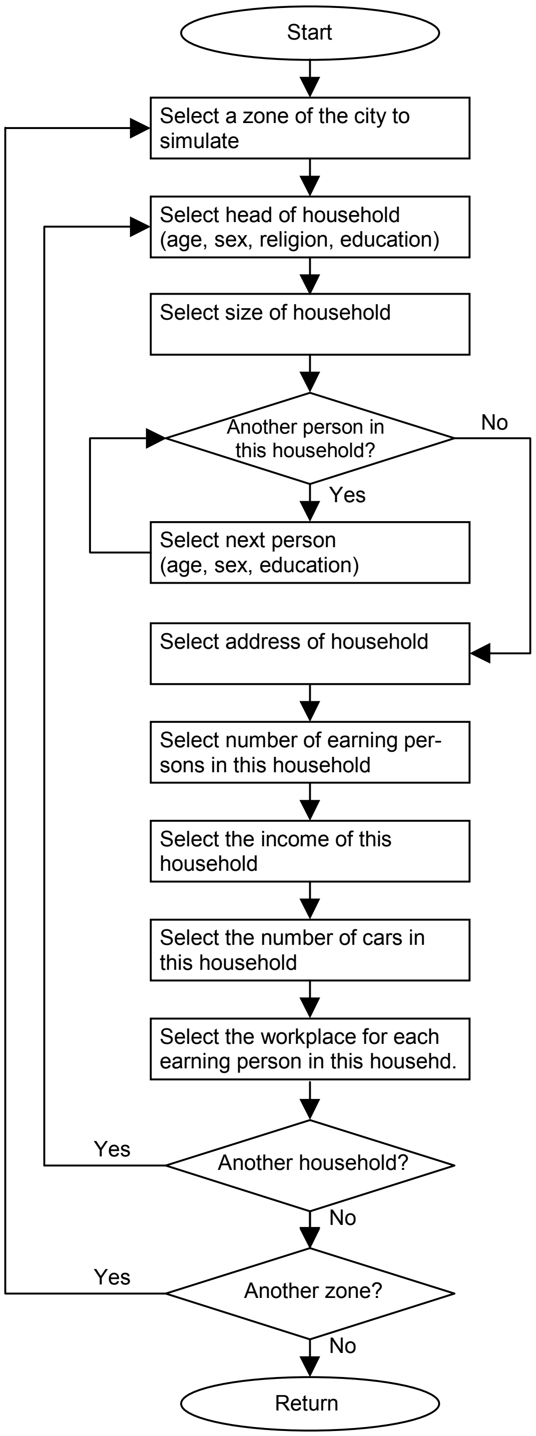


Figure 7-8 . The synthetic population generator

Table 7-2. Weighting factors for the age of the head of household

	Age																			
	0 -4	5 -9	10 -14	15 -19	20 -24	25 -29	30 -34	35 -39	40 -44	45 -49	50 -54	55 -59	60 -64	65 -69	70 -74	75 -79	80 -84	85 -89	90 -94	95 -99
m/f	0	0	0	1	47	73	87	94	98	97	88	85	87	88	77	42	22	10	3	1

Source: Central Bureau of Statistic of Israel (1999)

In most cases the second person is the lifetime companion of the first person of the household. Therefore the second person will have a similar age as the first person. If the first person is a woman, the second person often will be a man and on average he will be two years older. This is illustrated by the probability distribution in Figure 7-9. Vice versa, if the first person is a man, the second person mostly is a woman and two years younger. Of course this is only the most likely combination, all other combinations are possible, too. For instance, there might be two sisters living together in one household or a single-parent family.

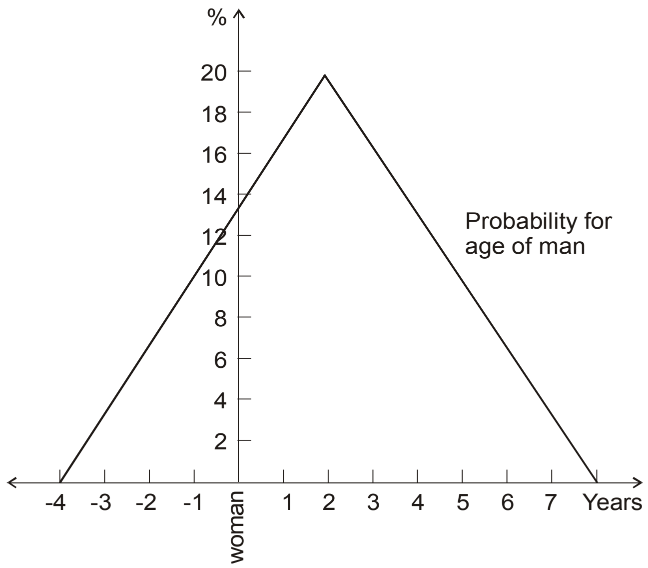


Figure 7-9. Probability for the age of the husband

The probabilities of Figure 7-9 are converted to weighting factors for the probabilities of the age groups in Table 7-1 (partners below 18 years of age are given a very low weight). By this way it is quite probable to select a suitable spouse for the first person. Occasionally, a child will be selected as second person, then a single-parent household is created. Other unlikely household combinations are also possible but are selected rarely. Generally, couples will be selected with the first and the second person.

After selecting the age group of the second person, the exact age (position 1 to 5 within the selected age group) has to be determined. While the exact age of the first person was selected by random choice, the exact age of the second person is selected depending on the most likely age as illustrated in Figure 7-9.

The third, fourth, and fifth person of the household are most probably children. On statistical average, the third person is 23 years younger than the 'mother' (the female person of persons #1 and #2), person #4 is 26 years younger and person #5 is 29 years younger (Möller 1982, 25). If there is no 'mother' among persons #1 and #2, the age of the children is referenced to the 'father', statistically the first child is 25 years, the second child 28 years and the third child 31 years younger than the 'father'. To implement these relationships, probability distributions like the one in Figure 7-9 are used to generate weighting factors for the probabilities represented in Table 7-1.

These assumptions make it possible to generate quite realistic family constellations. For example, further household members can be children, grandparents, siblings of the parents or friends living in the household. As it is difficult to determine a probable relationship to household members #1 to #5, persons #6 and following are selected with random age and gender.

Religious Affiliation

The synthetic population for Netanya distinguishes between two religious affiliations: ultra-orthodox and non ultra-orthodox. It is assumed that other religions than ultra-orthodox do not noticeably influence travel behaviour.

Unfortunately the share of ultra-orthodox persons is only available for the eight regions and not for 54 zones in Netanya (see Section 7.1). Therefore the share of ultra-orthodox persons of the region is used for the zones in that region. Since ultra-orthodox households tend to be significantly larger than other households, zones with a bigger average household size get a higher-than-average share of ultra-orthodox persons, and zones with a lower average household size got a smaller-than-average share of ultra-orthodox persons. On average, the shares of ultra-orthodox persons of the zones in one region match the share of the region.

The religious affiliation is selected for the first person of each household only. As there are hardly any mixed households of ultra-orthodox and non ultra-orthodox persons, the religious affiliation of the first person is assumed also for the further persons of the household. The religious affiliation is selected randomly based on drawing with replacement.

Education

The education of each person is determined depending on age and gender. The level of education describes the last school attended, distinguishing in academic, post-secondary, general secondary, vocational or agricultural secondary, primary or intermediate, no school education or still attending school, and yeshiva, the school most ultra-orthodox men are visiting. It is selected by drawing with replacement.

Since there were no data describing the educational situation in Netanya are available, data for Israel are used. To differentiate the educational level by gender, German data are used. Education is drawn with replacement. Table 7-3 shows the distribution of education for non ultra-orthodox persons:

Table 7-3. Probabilities of type of education of non ultra-orthodox persons

	Age	Academic	Post-secondary	General secondary	Vocational or agricultural secondary	Primary or intermediate	No school education or still attending school
male	0- 9 years	0	0	0	0	0	100
	10-14 years	0	0	0	0	95	5
	15-19 years	0	16	220	72	2,481	295
	20-24 years	83	446	1,217	416	752	90
	25-29 years	703	677	1,326	599	474	53
	30-34 years	1,320	771	1,560	780	535	62
	35-39 years	1,346	742	1,342	826	501	59
	40-44 years	1,335	682	1,106	813	414	50
	45-49 years	1,400	623	986	939	408	47
	50-54 years	1,087	394	846	923	433	53
	55-59 years	1,351	408	1,031	1,550	566	65
	60-64 years	956	281	771	1,569	531	65
	65 and more	1,835	565	1,735	3,446	790	95
female	0- 9 years	0	0	0	0	0	100
	10-14 years	0	0	0	0	95	5
	15-19 years	0	27	188	23	2,276	698
	20-24 years	203	661	1,161	148	577	177
	25-29 years	1,152	925	1,489	235	422	128
	30-34 years	1,698	1,074	1,785	301	466	141
	35-39 years	1,673	1,000	1,654	348	456	139
	40-44 years	1,592	861	1,287	409	461	144
	45-49 years	1,401	736	1,080	517	469	146
	50-54 years	870	417	945	495	427	130
	55-59 years	904	367	1156	829	489	150
	60-64 years	559	242	805	896	494	150
	65 and more	1,177	560	2,638	3,119	1,484	454

Source: Calculations based on Central Bureau of Statistic of Israel (1999) and Statistisches Bundesamt (1999)

All ultra-orthodox men receive yeshiva education. It is assumed that ultra-orthodox women and children have no school education or are still attending school. Special attention is given to the education of the second person of each household. Since the education of lifetime companions tends to be similar, it is tried to select an education for the second person comparable to the education of the first person. There are are up to five attempts to select an education for the second person either one level lower, the same, or one level higher than the education of the first person.

Household Size

Household size is drawn without replacement to guarantee that the number of households and persons in each zone is exactly as given by the zonal data. Household sizes between one and ten are considered. For instance, the following household sizes are given for zones 111, 112 and 122 (Table 7-4):

Table 7-4. Household sizes by zone

Zone	Household size										
	1	2	3	4	5	6	7	8	9	10	∑
111	128	136	136	104	143	88	32	9	8	8	792
112	174	223	211	235	174	136	62	13	2	0	1230
122	350	367	252	317	201	118	35	18	0	0	1658
…											

Source: Micro Census Netanya (1995)

Household size is drawn without replacement. The household size depends on the age of the first person and its religious affiliation. According to a typical life cycle, a head of household younger than 25 and older than 65 years tends to have smaller households, while a head of household aged between 25 and 65 years tends to have a bigger household. The second mayor influence is the religion of the household. Statistically ultra-orthodox households are significantly bigger than non ultra-orthodox households. Table 7-5 shows the weighting factors applied to the probabilities of Table 7-4:

Table 7-5. Weighting factors for household size

Age of head of household		Household size									
		1	2	3	4	5	6	7	8	9	10+
Non ultra-orthodox	18-20	409	462	122	1	1	1	1	1	1	1
	21-25	154	151	344	259	61	10	9	10	1	1
	26-45	7	17	81	345	283	187	55	20	2	2
	46-65	20	54	113	301	299	147	43	16	4	4
	66-75	200	294	159	173	135	13	12	13	1	1
	over 75	409	462	122	1	1	1	1	1	1	1
Ultra-orthodox	18-20	138	403	267	186	1	1	1	1	1	1
	21-25	6	16	91	353	231	91	127	83	1	1
	26-45	1	1	5	109	252	388	180	39	14	11
	46-65	1	1	8	107	300	344	159	35	25	20
	66-75	7	25	34	192	420	96	134	88	1	1
	over 75	138	403	267	186	1	1	1	1	1	1

Housing Location

An 'address' or housing location in the synthetic population is a row (y-coordinate) and a column (x-coordinate) in the system of raster cells. The population of each raster cell is determined from the total population of the zone in which the raster cell is located and the land use of the raster cell (see Section 7.3 for the methodology of disaggregating zonal population to raster cells). At the beginning of the creation of the synthetic population, the number of persons living in each raster cell is known.

Because the zone in which the household lives is already known, the choice of a housing location is constrained to the raster cells in that zone. The choice of a raster cell in the zone occurs by random choice. If that cell has as many or more people than the household size of the household, the cell is selected. In order to distribute exactly as many persons to each raster cells as there are people living in that raster cell, the number of persons in the cell is reduced by the household size (drawing without replacement). If there are not enough persons for the household in the raster cell, another cell is selected by random choice.

Figure 7-10 shows the resulting distribution of persons by raster cell. The shading indicates population density, i.e. number of persons per raster cell – the numbers have to be multiplied by four to indicate persons per hectare.

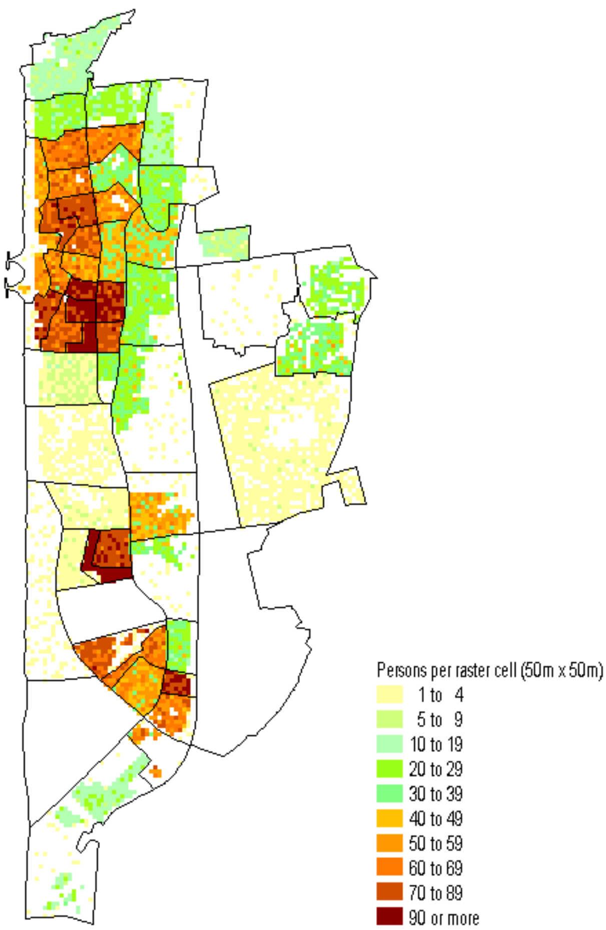


Figure 7-10. Synthetic population density in Netanya by raster cell

Earning Persons

To determine the number of earning persons of a household, first the religious affiliation is checked. If the household is ultra-orthodox, the weighting factors of the first line of Table 7-6 used to select the number of earners. If the household is not ultra-orthodox the number of children is checked. If there are children in that household, the corresponding line for 'Families with children' is used, differentiating in children under 4 years and children 4-10 years. Only if the household is not ultra-orthodox and does not have children younger than 11 years, the level of education determines which weighting factors are used to determine the number of earners. Since households with higher education tend to have more earning persons, the educational level of person #1 and #2 is checked. The higher education of both is taken as educational level of this household. Then the number of earning persons for that household is selected by drawing with replacement.

Table 7-6. Weighting factors to select the number of earning persons

Household group		Number of earning persons			
		0	1	2	3
Ultra-orthodox households		186	182	97	74
Children	Families with children (<4 years)	56	590	504	486
	Families with children (4-10 years)	126	633	644	600
Education	0-8 years of schooling (primary & intermediate)	284	311	243	300
	9-12 years of schooling (secondary)	280	593	1,81	1,96
	13-15 years of schooling (post-secondary)	61	124	273	274
	16 and more years of schooling (academic)	59	128	313	302

Source: Central Bureau of Statistic of Israel (1999) and own assumptions

Household Income

Household income is expressed as monthly income in NIS. Household income is influenced mainly by the number of earning persons and the level of education. First, the position of the household in the income distribution (in deciles) is drawn without replacement to ensure that income distribution of the synthetic population corresponds to the income distribution of the actual population. Within the selected income decile the exact amount of the income is selected randomly. The Central Bureau of Statistics of Israel provides data of income deciles for Israel. This average was taken and distributed over the zones of Netanya; evidence to disaggregate the Israel data to Netanya zone data was given by 'rooms per person', 'education', 'car ownership', and 'density" given for each zone. The result is indicated for three zones in Table 7-7.

Table 7-7. Income deciles by zone

Zone	Upper limit for … decile (NIS)									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
111	2,888	3,883	4,769	5,714	6,783	8,001	9,577	12,047	16,112	29,196
112	2,583	3,473	4,265	5,110	6,066	7,155	8,565	10,773	14,409	26,110
122	2,524	3,393	4,167	4,993	5,927	6,992	8,369	10,528	14,080	25,514
…										

Sources: Central Bureau of Statistic of Israel (1999) and Micro Census Netanya (1995)

According to the definition of deciles, ten percent of the households in each zone are allocated to each decile. The income is selected by drawing without replacement. To select an income for a household, first the education of the household is checked as households with higher education tend to have higher incomes. The person (of persons #1 and #2) with the higher education determines the educational level of the household. Next the number of earners in the household is checked, as more earners increase the total household income. Tables 7-8 and 7-9 present the weighting factors to take account of the influence of education and number of earners. The exact amount is selected on a random base.

Table 7-8. Weighting factors to represent the influence of education on income

Education	Income decile									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Academic	1	1	1	1	1	36	117	470	829	933
Post-secondary	1	4	2	15	35	178	493	348	143	52
General secondary	24	172	187	323	647	581	281	170	13	11
Vocational & agricultural secondary	307	347	463	559	280	176	104	10	12	1
Primary and intermediate	351	340	318	96	34	26	2	1	1	1
Did not attend school	149	96	23	5	2	1	1	1	1	1
Yeshiva	166	40	6	1	1	1	1	1	1	1

Source: Central Bureau of Statistic of Israel (1999)

Table 7-9. Weighting factors to represent the influence of number of earners on income

Number of earners	Income decile									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
no earner	100	75	50	25	1	1	1	1	1	1
1 earner	1	50	75	100	75	50	25	1	1	1
2 earners	1	1	1	25	50	75	100	75	50	1
3 earners	1	1	1	1	1	1	25	50	75	100

Number of Cars

The number of cars of a household is determined as a function of its income and the number of persons that are able to drive. One household can own up to six cars. The number of cars is selected by drawing without replacement. Table 7-10 shows this distribution for three sample zones:

Table 7-10. Number of households with 0, 1, 2, and 3 or more cars by zone

Zone	0 car	1 car	2 cars	3 or more cars
111	224	367	73	128
112	482	495	53	200
122	829	497	116	216
…				

Source: Micro Census Netanya (1995)

Persons between 18 and 80 years are assumed to be able to drive. Households with more persons who are able to drive tend to have more cars. In addition, income is considered to influence the number of cars, as households with a higher income tend to have more cars (Mogridge 1983, 147). Tables 7-11 and 7-12 show the influence of the number of persons able to drive and of income on the number of cars.

Table 7-11. Weighting factor to represent the influence of age on the number of cars

Number of cars	Number of persons 18-80 years								
	0	1	2	3	4	5	6	7	8+
No car	1,000	750	500	250	1	1	1	1	1
1 car	1	250	500	1,000	750	500	250	1	1
2 cars	1	1	250	500	1,000	750	500	250	1
3 and more cars	1	1	1	250	500	1,000	1,000	1,000	1,000

Table 7-12. Weighting factor to represent the influence of income on the number of cars

Number of cars	Income decile									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
No car	928	828	679	559	509	410	290	300	300	390
1 car	70	170	310	420	470	540	610	580	560	270
2 car	1	1	10	20	20	40	90	110	120	290
3 or more cars	1	1	1	1	1	10	10	10	20	50

Source: Mogridge 1983, 147 and Micro Census Netanya (1995)

Place of Work

For every earning person, a place of work is selected from one of 26 locations within Netanya and other targets in Israel. Statistical data are available for the eight statistical regions in Netanya (see Section 7.1). For each region, the share of workers commuting to one of the 26 work place destinations is given. Based on the region the household is located in, the destination is randomly drawn with replacement.

Table 7-13. Weighting factors to select work place location by region

Destinations	Origins							
	Ramat Poleg	Kiryat Nordow	Dora/ Azorim	East Netanya	Ramet Chen/ Ben Zion	Center/ South Herzl	Center/ North Herzl	Sanz
Haifa and the North	2.43	3.98	4.15	2.61	4.78	3.97	2.98	6.57
East Shomron	0	0.35	0.64	0	0	0.15	0.14	0
Jerusalem	0	0.71	0.22	0.3	0.43	0.54	0.51	0
South	0	0.52	0.4	0.3	0	0.45	0.27	2.6
Villages near Netanya	1.04	4.03	4.79	8.43	4.27	4.91	5.48	2.6
Herzelia/Ranana/ Kfar-saba	9.25	7.71	7.36	8.21	2.11	4.77	5.68	7.27
Petach Tikva/ Ramat Gan	0	0.64	2	1.29	2.37	1.22	1.53	0
Givataim/Beney Brak/Ramat Gan	9.13	2.79	2.22	1.78	3.15	3.49	3.42	7.79
Kiryai Ono/Yahud	0	0.11	0.42	0	0.6	0.29	0.43	0
Lod area	0	0.5	0.44	1.21	0.6	0.36	0.4	0
Tel Aviv	15.61	17.4	9.71	6.28	9.83	10.01	9.17	7.79
Bat Yam/Holon	0	0.84	0.86	0	1.34	0.34	0.58	0
Rishon Lezion	1.04	0.11	0.22	0	0	0.33	0.12	2.6
Rechovot/Ashdod	0	1.46	1.06	0	0.69	1.33	0.79	2.6
Netanya area	0	10.56	12.24	13.69	14.57	10.11	12.27	19.55
Police/Army Base	2.08	0.57	0.9	0.57	0	0.77	0.72	0
Abroad/unknown	7.4	0.28	0	0	0	0.29	0.33	0
Ramat Poleg	9.83	0.85	1.32	0.49	0.99	1.13	0.38	0
Kiryat Nordow	0	5.89	0.9	1.93	2.37	1.69	1.73	0
Dora/Azorim	1.85	2.36	7.6	1.7	2.24	1.85	0.99	0
East Netanya	3.12	5.3	7.65	13.46	6.29	4.24	5.44	0
Ramet Chen/Ben Zion	3.24	0.73	1.34	0.3	4.61	1.42	0.8	0
Center/South Herzl	26.24	15.19	16.32	17.51	20.26	26.25	21.05	14.71
Center/North Herzl	6.36	5.78	6.98	9.83	10.26	12.1	17.08	2.6
Sanz	0	0.53	1.3	2.19	1.72	1.82	1.86	23.36
Industrial zone	1.39	10.81	8.94	7.9	6.51	6.18	5.84	0

Source: Survey of Travel Behaviour in Netanya, 1995.

A work place is assigned for each working person. It is assumed that in general persons aged between 16 and 70 years are able to work. If possible, it is avoided to select a work place for the second person, as this person often stays at home to care for the household. Therefore, whenever there is at least one working person in a household, the first person gets assigned a work place. If there is more than one working person, the age of the last person of the household is checked. If the age of the last person is between 16 and 70, the person gets assigned a work place, if not, the second last person is checked, and so on. By this way it is tried to assign work places to other persons than the second person in the household.

7.4.3 The Change Submodel

Since the selection of age is drawn without replacement, it can happen that at the end of the simulation of the synthetic population of a zone there are still households to be generated but all adults in the zone are drawn and there are only children left. However, a realistic household cannot be composed from children alone. The Change subroutine ensures that at least one adult is available as head of household for every household.

Figure 7-11 explains the process of the Change submodel. the submodel branches out from the top box in Figure 7-8 labelled 'Select head of household'. The submodel checks whether there are any adults left to be drawn. If there is at least one adult left in the zone, the submodel is exited and the simulation continues. However, if all adults are already selected, the submodel takes one adult from a household that is already completed and exchanges the adult for a child.

First one already completed household (here called household x) is read in the list <hh.dat> which contains all simulated households. Then it is determined whether this household is a one-person-household. If so, household x cannot be used by the submodel because in a one-person-household there is no person that could be exchanged for a child. The submodel reads as many households in random order until a multiple-person-household (with two persons or more) is found.

Then one adult is drawn out of household x. The programme selects the last adult in the household to ensure that relatively common family structures are retained. For instance, in Figure 7-11 both parents are left in the household, as are the two children. However, the 32-year-old person #5, perhaps a friend living in that household, is exchanged so that a realistic family structure is maintained.

For the same position that was occupied by the adult in the household a child is drawn from the remaining persons in the zone and assigned to the household. The corrected description of the household is written to the database, including the corresponding correction in the list of persons <pp.dat>. The adult that has been taken away from household x is free to become the head of household of the next household generated.

The Change submodel is needed only for the last households in each zone, because up to that time there are always enough adults to be selected in the zone. Test runs have shown that the Change submodel is needed in the last 10 to 15 percent of households of each zone.

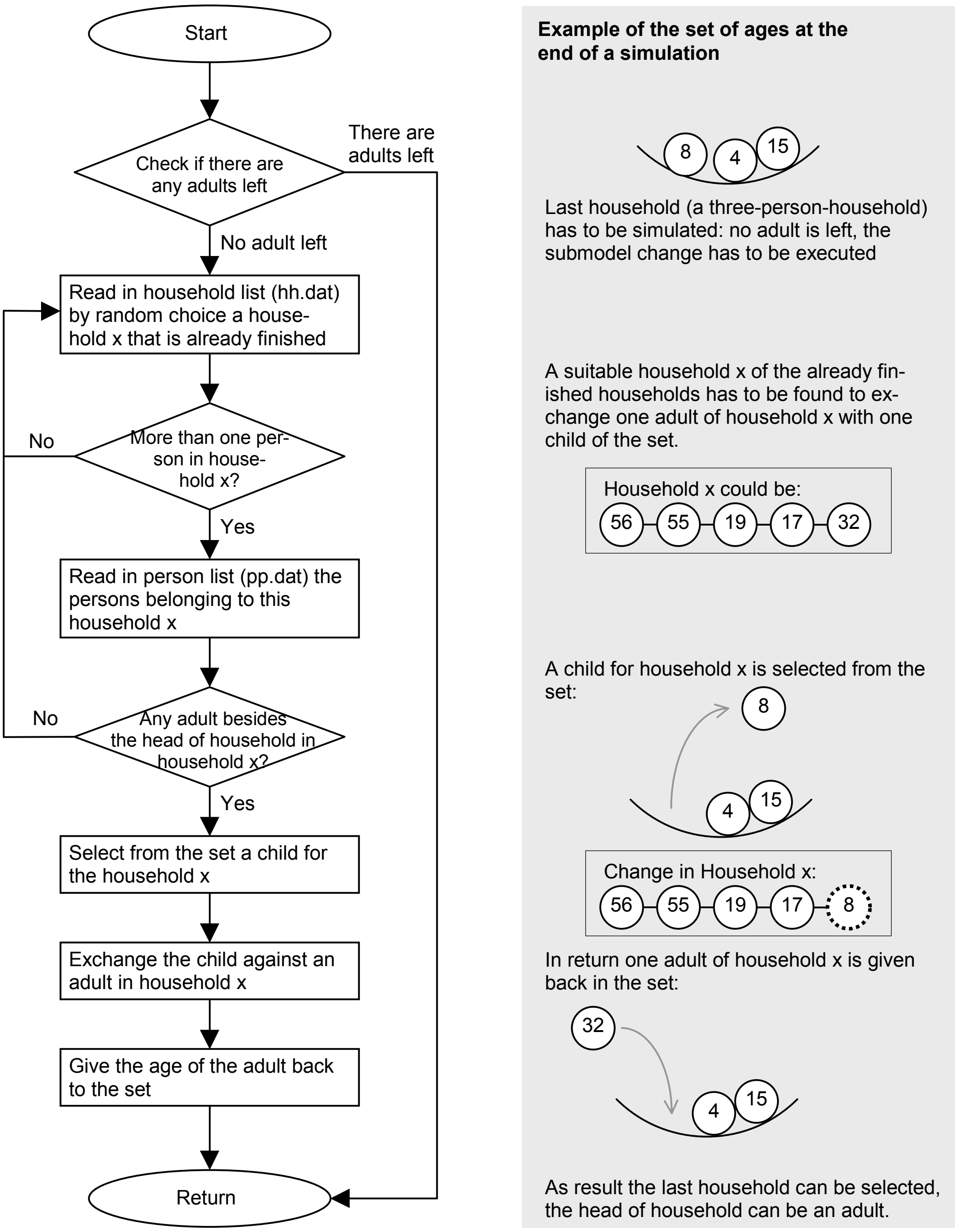


Figure 7-11. Structure of the Change submodel

7.5 Output

The result of the synthetic population generator programme are two lists: a list of households and a list of household members: All information about households is contained in the file <hh.dat>. All information about the persons is contained in the file <pp.dat>. The two files are linked by the corresponding household numbers and person numbers.

Figure 7-12 presents excerpts of the household file <hh.dat>. Each line describes one household. The first field contains the sequential number of the household. The next field contains the zone number; in the case of the first household, Zone 111. Then the columns (x-coordinates) and rows (y-coordinates) of the raster cell in which the household lives is shown, in this case the 79th cell in the 65th row. Next the monthly gross income in NIS of the whole household is given; the first household in zone 111 has a monthly gross income of 6,115 NIS. The next field contains the number of earners in the household, in this case two earners. Next the number of cars owned by the household is shown; the first household has one car. Then the household size is given; the first household is a three-person household. The following numbers are the sequential numbers of the three persons of the household.

Figure 7-13 presents excerpts from the person file <pp.dat>. Every line in this file describes one person. As the first household is a three-person household (as shown in <hh.dat>), the first household is represented in the person file <pp.dat> by three lines. The first number in each line is the sequential number of the person and the second number is the number of the household. These two numbers correspond to the person number and the household number in <hh.dat>. The next field contains the age of the person, followed by the gender, where 1 means male and 2 means female. So the first household consists of a couple aged 23 and 22 years. The next number indicates the religious affiliation of the person: 1 means non ultra-orthodox and 2 stands for ultra-orthodox. The following number indicates the level of education of the person (1 = academic, 2 = post-secondary, 3 = general secondary, 4 = vocational and agricultural secondary, 5 = primary and intermediate, 6 = no school education or still attending school, 7 = Yeshiva). The last number indicates the place of work, if any.

Figures 7-14 to 7-18 present examples of the spatial distribution of household attributes of the synthetic population:

- Figure 7-14 shows population density (persons per raster cell – the numbers have to be multiplied by four to indicate persons per hectare) The two population centres of Netanya, Herzl South Center and Dora Azorim, stand out against the low density suburbs in the North, East and South. There are still large areas of unused land in Netanya.

- Figure 7-15 shows the significant concentration of population with ultra-orthodox religious orientation north of the city centre in Kiryat Zans.

- Figure 7-16 shows average household size. There is a clear relationship between population density (Figure 7-14) and household size, In the high-density areas of Herzl South Center and Dora Azorim, households tend to be smaller, whereas larger household sizes are found in the suburban low-density quarters. Also the residential areas in Kiryat-Zans with a concentration of ultra-orthodox population (Figure 7-15) show above-average household sizes.

- Figure 7-17 shows the spatial distribution of household income. It can be seen that higher-income households prefer to live in low-density residential suburbs, but also along the seashore. There is a residential area with very high average incomes at the southern fringe of the urban area.

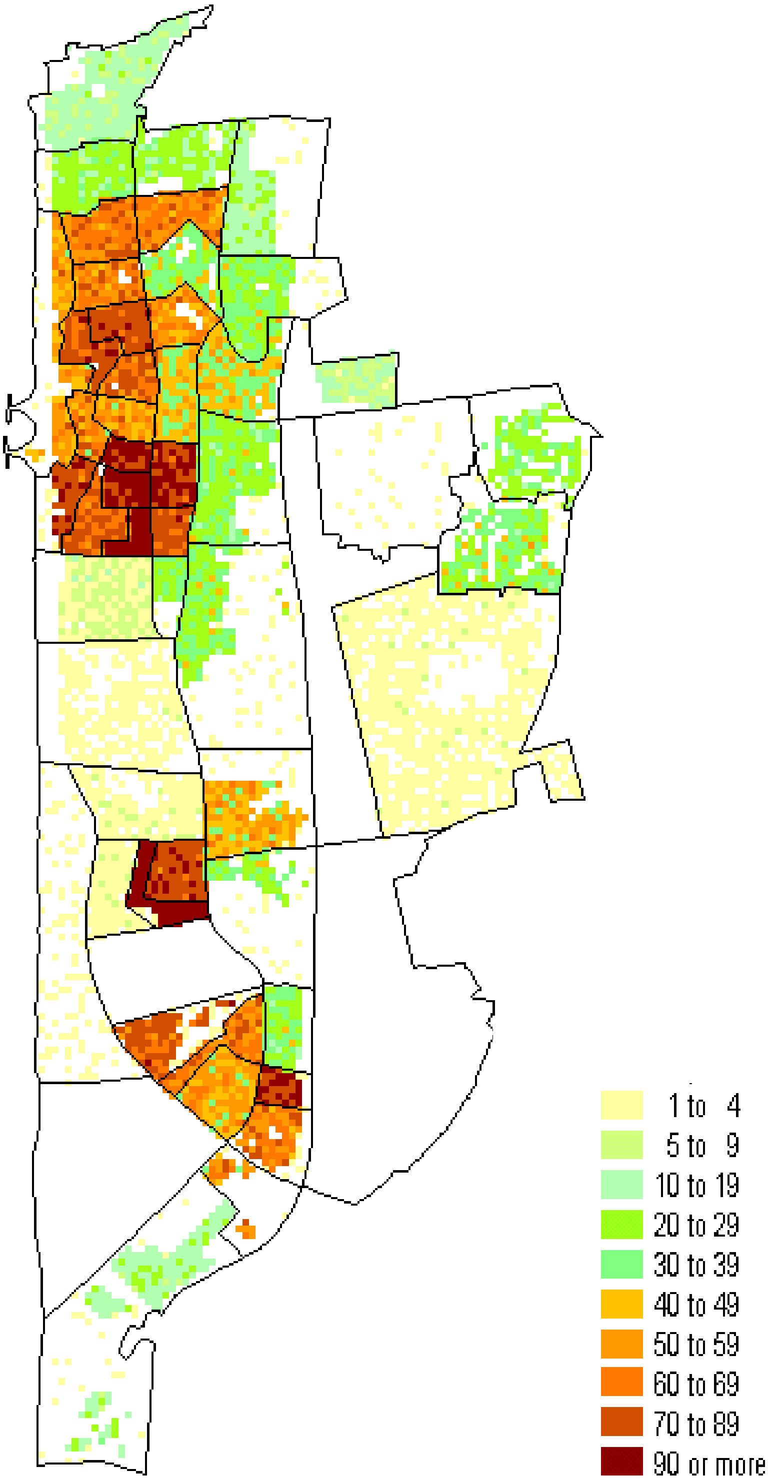
- Figure 7-18 shows the distribution of car ownership. This map clearly reflects the distribution of incomes of Figure 7-17 but also lower car ownership in the high-density residential areas.

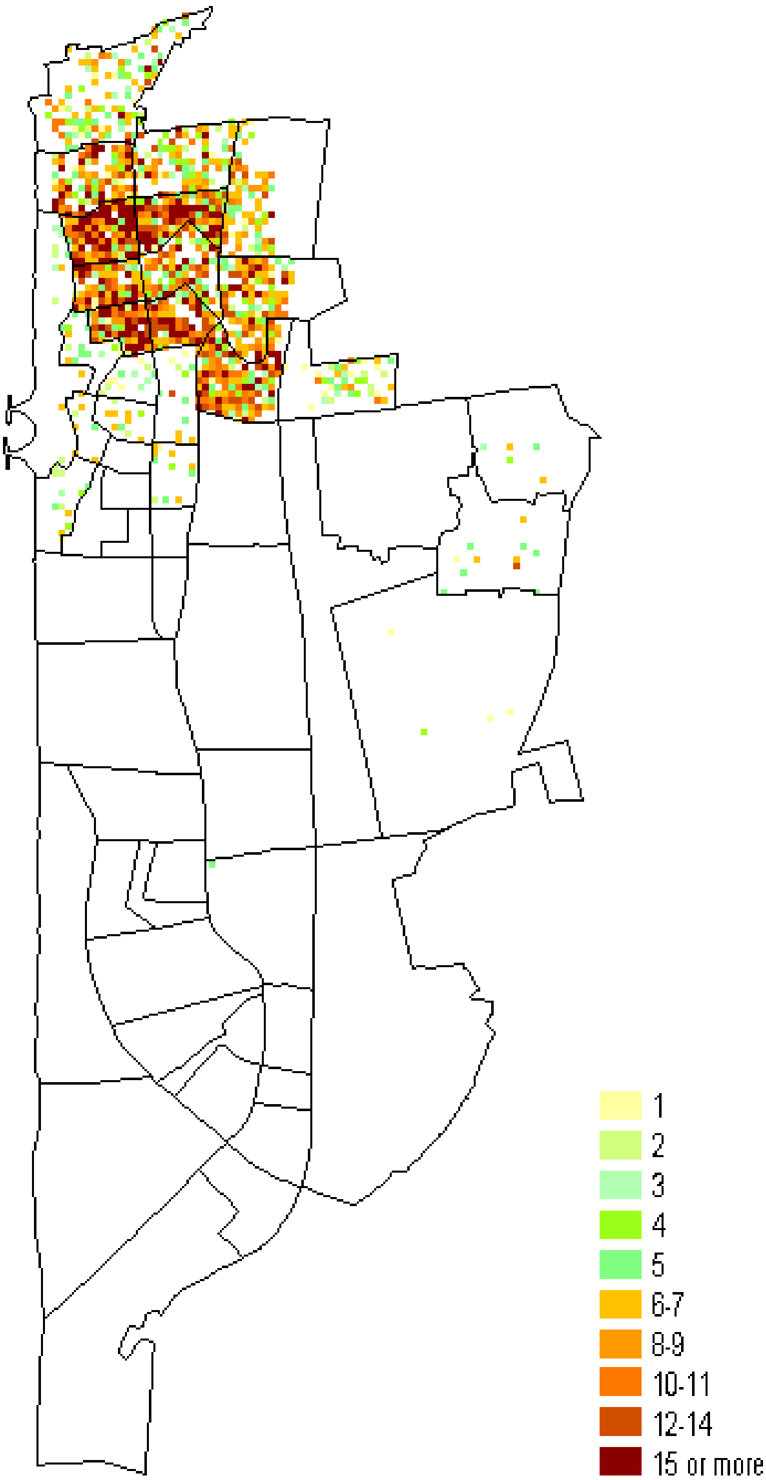
# of household	Zone	Column (x-coordinate)	Row (y-coordinate)	Income	Number of earners	Number of cars	Household size	Person #1	Person #2	Person #3	Person #4	Person #5	Person #6
1	111	79	65	6115	2	1	3	1	2	3			
2	111	75	69	4307	0	0	2	4	5				
3	111	75	67	9516	3	1	5	6	7	8	9	10	
4	111	78	65	5215	2	1	4	11	12	13	14		
5	111	77	69	6956	1	0	4	15	16	17	18		
6	111	73	67	10215	3	1	3	19	20	21			
7	111	78	63	6581	1	1	3	22	23	24			
8	111	78	66	8436	0	1	5	25	26	27	28	29	
9	111	81	63	6331	1	1	2	30	31				
10	111	77	65	8564	0	1	5	32	33	34	35	36	
11	111	81	74	8705	2	1	5	37	38	39	40	41	
12	111	85	76	4942	2	1	4	42	43	44	45		
...													
1000	112	81	85	8509	2	1	4	3776	3777	3778	3779		
1001	112	83	87	6896	1	1	4	3780	3781	3782	3783		
1002	112	82	88	10080	3	1	6	3784	3785	3786	3787	3788	3789
1003	112	70	78	5532	1	0	4	3790	3791	3792	3793		
1004	112	82	81	4680	2	0	2	3794	3795				
1005	112	78	81	3263	0	1	6	3796	3797	3798	3899	3800	3801
1006	112	80	80	8123	2	0	4	3802	3803	3804	3805		
1007	112	70	86	4024	0	0	2	3806	3807				
1008	112	83	89	9444	2	1	6	3808	3809	3810	3812	3813	3814
1009	112	70	82	5522	1	0	1	3815					
1010	112	77	82	3599	1	1	5	3816	3817	3818	3819	3820	
1011	112	69	81	3218	1	1	4	3821	3822	3823	3824		
1012	112	79	81	3496	1	0	5	3825	3826	3827	3828	3829	
...													
44600	336	20	191	5242	1	3	1	138612					
44601	336	32	190	3933	1	3	1	138613					
44602	336	15	198	3032	1	3	4	138614	138615	138616	138617		
44603	336	19	190	4273	0	3	5	138618	138619	138620	138621	138622	
44604	336	15	216	12981	1	3	3	138623	138624	138625			
44605	336	16	198	3108	0	3	6	138626	138627	138628	138629	138630	138631
44606	336	29	189	2995	1	3	3	138632	138633	138634			
44607	336	23	195	4072	1	5	6	138635	138636	138637	138638	138639	138640
44608	336	15	211	4776	1	3	4	138641	138642	138643	138644		
44609	336	14	196	5056	2	5	6	138645	138646	138647	138648	138649	138650

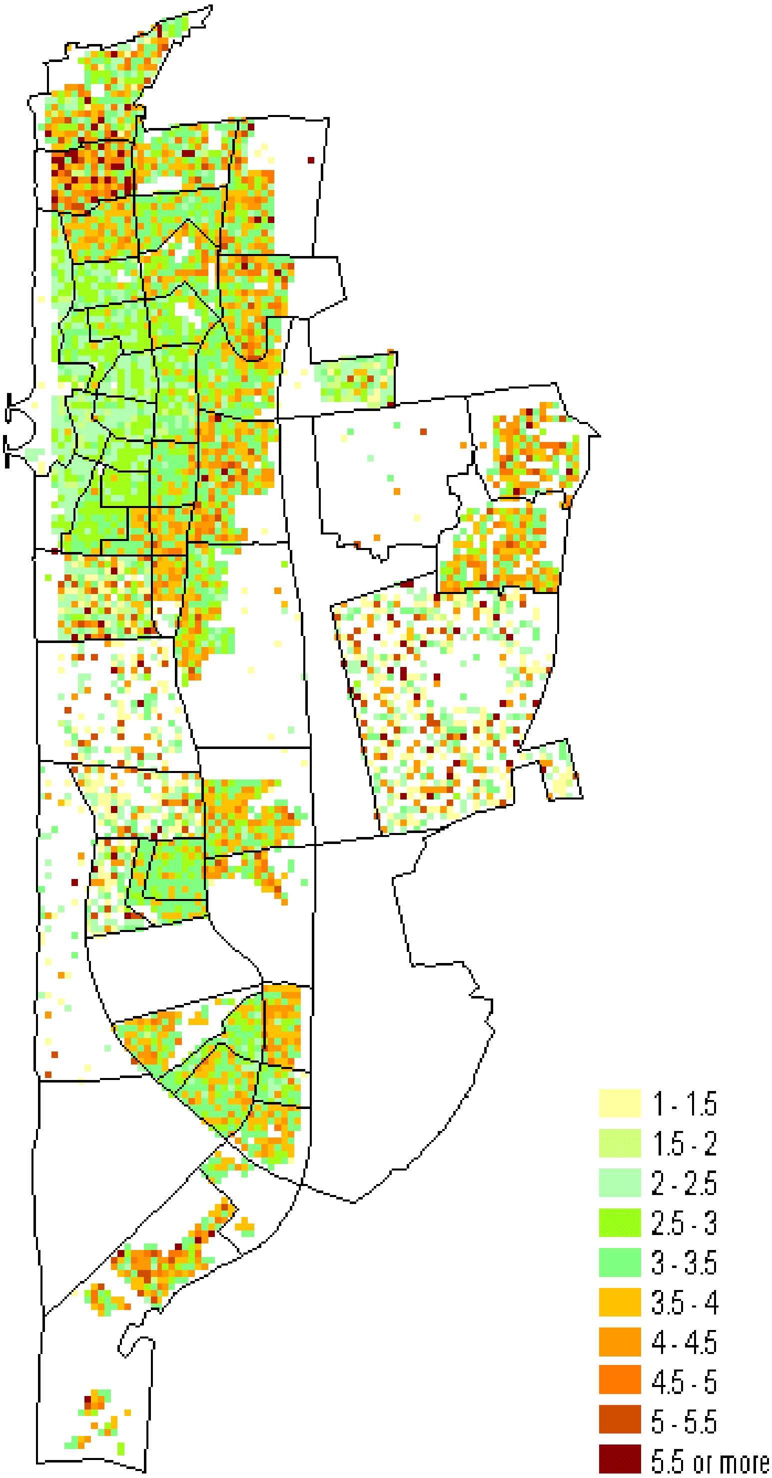
Figure 7-12. Excerpts from household file <hh.dat>

# of person	# of household	Age	Gender	Religion	Education	Place of work
1	1	44	1	1	1	23
2	1	41	2	1	1	9
3	1	17	2	1	5	
4	2	70	2	1	4	
5	2	73	1	1	3	
6	3	56	2	1	2	8
7	3	58	1	1	1	
8	3	24	2	1	2	23
9	3	23	1	1	3	15
10	3	20	1	1	3	
11	4	66	2	1	6	
12	4	66	1	1	5	21
13	4	42	2	1	6	
14	4	40	1	1	1	10
...						
3776	1000	37	2	1	1	5
3777	1000	44	1	1	2	15
3778	1000	13	1	1	6	
3779	1000	14	1	1	6	
3780	1001	23	2	1	3	
3781	1001	24	1	1	3	15
3782	1001	3	1	1	6	
3783	1001	1	2	1	6	
...						
138646	44608	53	2	1	4	4
138647	44608	11	2	1	5	
138648	44608	10	1	1	5	
138649	44608	12	2	1	5	
138650	44609	59	2	1	5	5
138651	44609	61	1	1	5	14
138652	44609	13	2	1	5	
138653	44609	7	1	1	6	
138654	44609	6	1	1	6	
138655	44609	5	2	1	6	

Figure 7-13. Excerpts from person file <pp.dat>


1 to 4
5 to 9
10 to 19
20 to 29
30 to 39
40 to 49
50 to 59
60 to 69
70 to 89
90 or more


1
2
3
4
5
6-7
8-9
10-11
12-14
15 or more


1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
5 - 5.5
5.5 or more

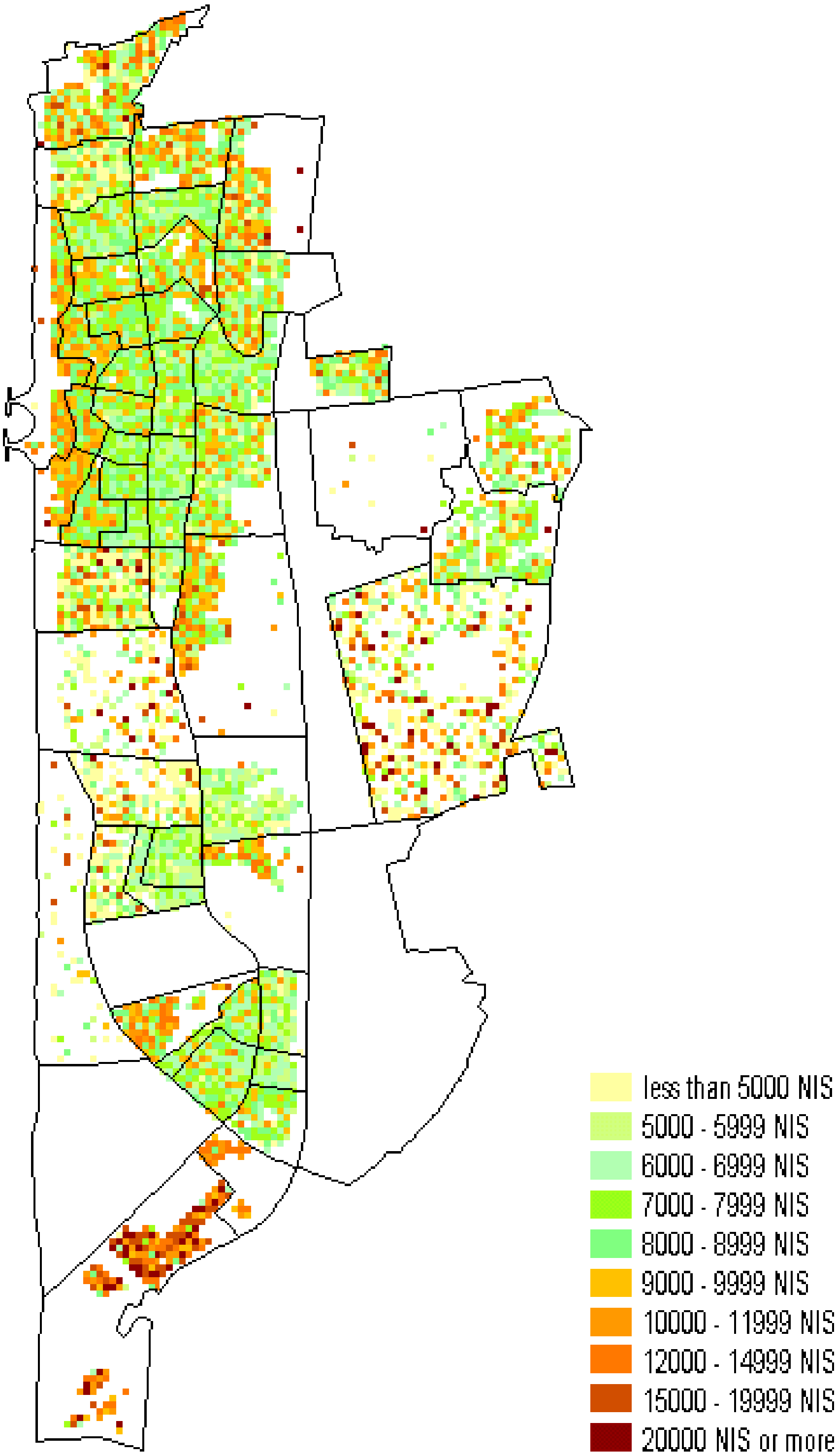


Figure 7-17. Average household income

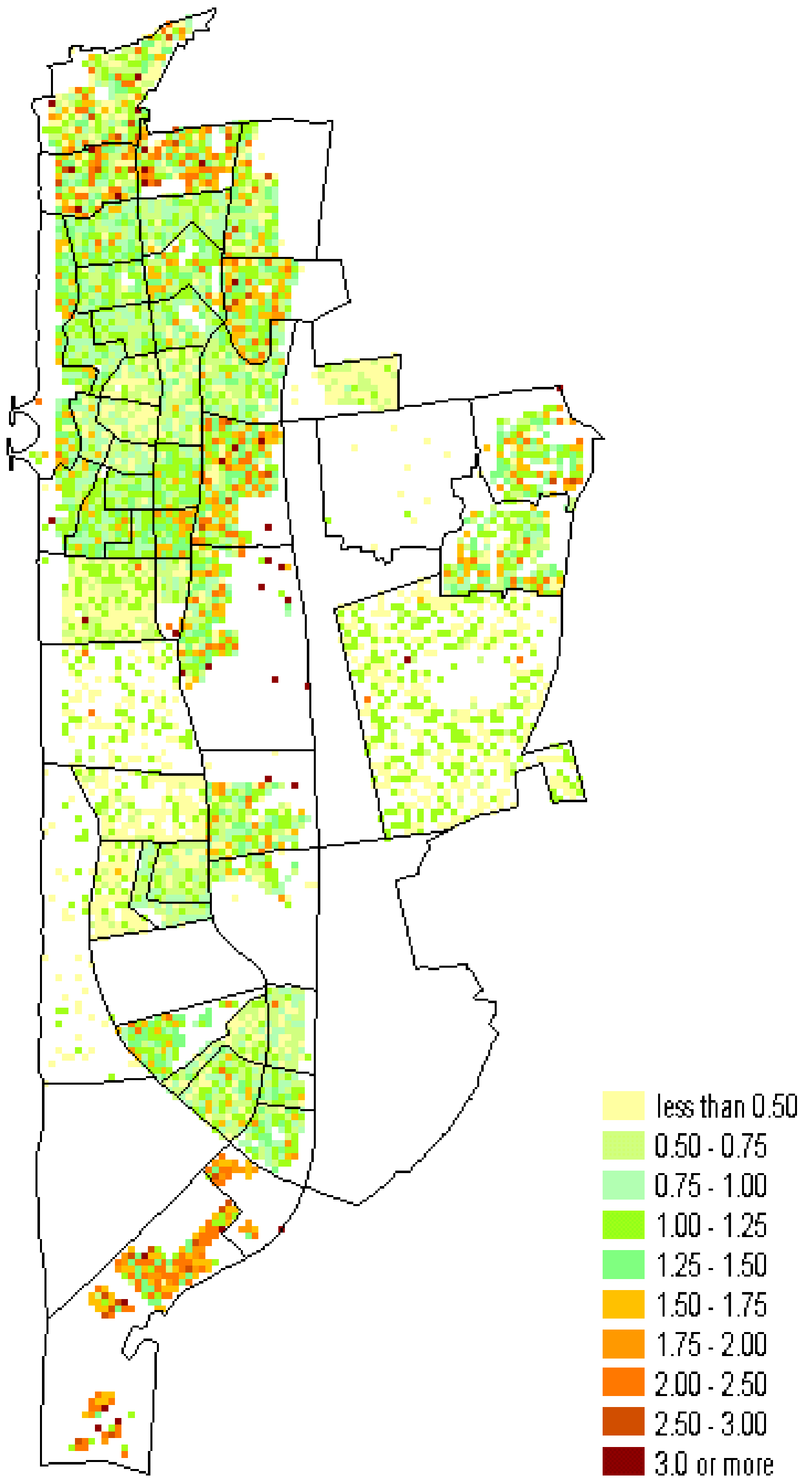


Figure 7-18. Car ownership (number of cars per household)

7.6 Limitations

Since every model is a simplification, the synthetic population has its limitations as well. On the one hand, features that are not absolutely necessary for the travel model are missing. For instance, whether a couple is married or not is not expected to significantly influence its travel behaviour, therefore this information is not taken account of. On the other hand, there are features that would be important to know, but which because of limitations of the programme or lack of data have not been modelled.

For instance, age is drawn without replacement. At the beginning of the simulation ages are selected according to the household size and to other household members in order to generate families and other likely household structures. At the end of the simulation the set of ages is rather empty and only ages that are left can be selected. Therefore households at the end of a simulation become less likely. The Change submodel guarantees that at least one adult is member of each household. But as soon as an adult is found, the last household is built. Therefore it happens for instance that there are households with one young adult and five infants, a very improbable configuration.

Another example concerns the age structure of large households. When creating households, the programme seeks to generate as many family households (with parents and one or more children) as in the real world. Therefore in many cases the first two persons are a women and a man at similar age forming a couple. The following persons are likely to be children. The age groups of persons #3 to #5 are therefore weighted in a way that most of them will be in the age of children of persons #1 and #2. However, the age groups of persons #6 to #10 are not weighted, i.e. their age is selected randomly because it is difficult to say which is the relationship between them and persons #1 to #5. They could be also children of the couple, but they could also be a parent or a sibling of person #1 or #2 or they just could be a friend living in this household. All ages make in a way sense for persons #6 to #10. This does sometimes lead to unlikely age compositions of households. However, more than 80 percent of all households in Netanya have less than six persons.

In the last step, each working person is assigned a work place. This assignment currently occurs randomly and does not take account of the skills of workers, even though the education level of each worker is known. However, this information could not be utilised because there is no information about the type and skill requirements of the jobs in each work place area. It might also have been possible to take account of car ownership or car availability, as far-away work places are more likely to attract people with cars.

A final criticism is that the assignment of households to zones, and hence to raster cells, does not take account of the housing stock in each zone, although this information is available. This suggests that in a future version of the model not zonal population but dwellings might be disaggregated to raster cells, and that housing location would be determined by allocating households to dwellings, just like in the real housing market.

8 Conclusions and Future Work

Although the project could not achieve its initial goals, it produced tangible results which are significant steps towards the identification of promising policy packages for sustainable mobility in cities:

- *Qualitative analysis*. In the qualitative part of the project, the analysis of typical life styles in the Israeli society produced groups of similar location, activity and mobility behaviour, which may be used to classify households and individual in activity-based travel models with respect to activity and mobility patterns and the way their behaviour is affected by transport-related policy instruments. In the policy analysis, the direct, economic and distributional effects of policy instruments were analysed in qualitative terms in order to pre-select policy packages for the in-depth investigation with the simulation model.

- *Quantitative analysis*. In the quantitative part of the project, a method for generating a 'synthetic' population of households and household members from available aggregate (zonal and national) data was developed and applied to the case study city of Netanya. The result is a micro database of households characterised by household size, income, car ownership and residential micro location populated by household members characterised by age and gender, religious affiliation, level of education and, for economically active persons, place of work which statistically corresponds to all known one- and two-dimensional distributions of households and persons in the case study area.

However, these results fall short of accomplishing the original objectives of the project. In particular the following tasks were not accomplished:

- *Qualitative analysis*. In the qualitative part of the project, it was not possible to verify the hypothesised life style groups empirically in Netanya, except for a small non-representative survey among students. Moreover, the problem how to explain the life style groups using only demographic and socio-economic variables, which can be collected from published statistics and can be forecast using demographic forecasting techniques, was not solved. In the problem analysis, the intended qualitative cross-impact analysis of negative and positive interactions between individual policy measures was not undertaken, so that eventually no concrete policy packages for Netanya were proposed.

- *Quantitative analysis*. In the quantitative part of the project, only the first step in the modelling process, the generation of the synthetic population, was completed and applied. The activity-based microsimulation model of travel behaviour consisting of choice of activity pattern, choice of car ownership and availability, choice of destination, mode and route and assignment of travel flows to the network was only designed conceptionally but not applied to real data of Netanya. Therefore it was also not possible to link the travel model with the pre-existing environmental impact models and apply the integrated model to concrete policy packages for Netanya.

- *Integration of qualitative and quantitative analysis*. It was not possible to link the qualitative and quantitative parts of the project by (a) fully integrating the life styles identified in the qualitative part with the synthetic population generated in the quantitative part and (b) applying the model developed in the quantitative part to policy packages identified in the qualitative part.

The conclusion is that the successful development and implementation of a complete activity-based microsimulation urban travel model is a substantial task which far exceeds the very limited resources of the reduced project. However, the limited results achieved are steps towards such a model and will be used in future work of the investigators.

The Dortmund group has been successful in obtaining resources for a much larger project with similar objectives as the Netanya project. The multi-university project ILUMASS (Integrated Land-Use Modelling and Transportation System Simulation) funded by the German Ministry of Education and Research aims at embedding an existing microsimulation model of urban traffic flows into a comprehensive model system incorporating both changes of land use and the resulting changes in transport demand. The integrated model consists of modules for demographic processes, household formation, firm life cycles, residential and firm location, residential, commercial and industrial construction, car ownership and daily travel and goods transport. The contribution of the Dortmund group is to develop the microsimulation land-use component. Like the Netanya model, the model works with synthetic micro data aggregated from generally accessible public data. Study region for tests and first applications of the model is the urban region of Dortmund. The experience gained with the synthetic population generator for Netanya has already proven to be useful in the ILUMASS project.

In addition, efforts will be made to continue the co-operation with the Hebrew University and reinforce existing research links with the UrbanSim project at the University of Washington in Seattle (Waddell, 2000a; 2000b) within the recently established EU-funded transatlantic STELLA research network (Salomon et al., 2002).

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