DIVERSITY, ACCESSIBILITY AND ITS IMPACT ON VEHICLE OWNERSHIP AND RESIDENTIAL LOCATION CHOICES

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Abstract

The research objectives of this thesis are twofold. The first objective is to contribute to the measurement of the built environment and the subsequent relationship between the built environment and transport and land-use related decisions by individuals. On one hand there exists the need to describe, measure and design the built environment; on the other hand there is the economist’s perspective, that takes interest in what individuals and households value when making choices. The second objective is to provide insights in these factors for the city state of Singapore, given existing and newly generated data sets.

The mediating factor between transport and land-use is accessibility: the ability to perform activities. The deterrence to travel is captured with distance decay functions. Given Singapore’s urban environment, which is the result of stringent land-use planning, the question arises whether such a deterrence function measures the imposed spatial structure, individual’s preferences, or both. To investigate this, a series of distance decay functions by trip purpose and mode is estimated for Singapore and Switzerland.

The role of the representation of the pedestrian network is evaluated by generating different pedestrian networks and calculating walking distances along these different networks. It is shown that using pedestrian network distances, both over road centrelines and an advanced pedestrian network, strongly decreases the accessibility to jobs by foot and public transport.

The measurement of diversity is critically assessed and a new diversity index is proposed, that includes accessibility to desired destinations and does not penalize if there is an abundance of a single destination type, as usually is the case. This measure is calculated for both Singapore and the whole of Switzerland using a global points on interest database and network distances to these points of interests. The impact of this measure is assessed by evaluating the choice to walk in both countries by trip purpose. After correcting for socio-demographic characteristics, it is found that the constructed indices best explain home-based and work-based shop trips.
To evaluate residential mobility and location choice in Singapore a survey was newly developed and administered. This survey consisted of an incidence survey to identify recent movers and a longer, main survey, to obtain insight in the current dwelling, previous dwelling, search behaviour and most important social contacts.

The estimation of a nested logit model reveals that in Singapore couples without children tend to move and form a family after moving house. Single person household are more likely to rent a dwelling; owners are less likely to move.

A recurring challenge in location choice models is the size of the choice set. Descriptive analysis reveals that households search in a limited area and in a limited number of markets. A choice set generation algorithm is proposed that takes into account actual search preferences and uses residential transactions shows that the size of the universal choice set of residential alternatives is mainly influenced by the spatial and temporal dimension of the search process. Still, households report to only consider up to five dwellings in their search process for a new house.

Residential location choice models containing alternatives on the level of individual dwelling unit were estimated. Also, choice sets were evaluated that take into account households’ actual search preferences that include dwelling size, dwelling price and possible areas. Models including spatial variables describing the social environment, combined with choice sets only including alternatives within the preferred price range, perform best. In this case, the social environment consisted of variables describing a household’s average distance to work, the distance to their parents and the average distance to the locations where they most frequently meet their five closest contacts.

This leads to the conclusion that diversity and accessibility do matter for both Singapore and Switzerland for short term decisions such as the choice to walk and whether to own a vehicle. However, for long-term decisions, such as the choice for a dwelling, no significant effect could be found: the activity spaces of households proved to be significant in explaining the choice of residence instead of variables describing the immediate built environment. Nevertheless, in order to support the usage of active modes this makes it even more relevant to provide for a diverse range of amenities in the immediate environment of residences to curb the use of motorized transport.
Zusammenfassung


Zusammenfassung


Das Umzugsverhalten und die Entscheidung zum Wohnstandort wird basierend auf einer neu entwickelten Befragung untersucht. Diese Befragung besteht aus einer Kurzumfrage, um Personen zu identifizieren, die kürzlich umgezogen sind und einer längerer Umfrage, in welcher Daten zum aktuellen und bisherigen Haushaltsstandorte, das Vorgehen bei der Suche sowie die räumliche Charakteristik des sozialen Netzwerks erhoben werden.


Für die Modelle zur Wahl des Wohnstandorts geschätzt werden die Alternativen auf der Ebene einzelner Wohnungen beschrieben. Die Auswahl der Alternativen berücksichtigt dabei die die tatsächlichen Suchpräferenzen der Haushalte berücksichtigen, wie z.B. Wohnungsgröße, Wohnungspreis...

Dies führt zur Schlussfolgerung, dass Diversität und Erreichbarkeit sowohl in Singapur wie auch der Schweiz wichtig sind für kurz- und mittelfristige Entscheidungen wie zu Fuss unterwegs zu sein oder ein Fahrzeug zu besitzen. Dies erlaubt die Schlussfolgerung, dass zur Förderung der aktiven Mobilität es wichtig ist in Fussdistanz von Wohngebieten verschieden Aktivitätsorte erreichen zu können. Für langfristig angelegte Entscheidungen wie Wohnungswahl konnte jedoch kein Effekt bezüglich der Diversität und fussläufigen Erreichbarkeit gefunden werden: Hier beeinflusst dafür die räumliche Verteilung von sozialen Kontakten die Wohnortwahl signifikant.
Acknowledgements

Singapore in general, and the Future Cities Laboratory specifically are truly remarkable places. The colleagues at FCL, and the almost endless flow of visitors and accompanying ideas passing through Singapore have helped to shape many of the ideas in this thesis. 

First and foremost I would like to thank Prof Kay W. Axhausen for his guidance and freedom to work on this thesis. His knowledge of transport planning and surveys is incomparable, and the appetite for knowledge beyond his field is inspirational. I would not have been in Singapore would it not be for Dr Alex Erath, who as an enthusiastic project leader continuously provided me with opportunities, ideas for research and contacts in Singapore and abroad, and helped to develop myself beyond the thesis research in a range of projects. As a friend I would like to thank him for always being available for matters beyond research. Also, I would like to thank Prof. Harvey Miller for our discussions, and providing me with the necessary time to finish this thesis.

My studies and employment were funded by the Singaporean National Research Fund and CREATE. I am immensely grateful for this opportunity. Also, I value the ongoing collaboration with the Land Transport Authority and Urban Redevelopment Authority. Not only have they provided FCL with a range of data sets, but also with insights in transport and urban planning in Singapore in many formal and informal discussions.

Of the many people at FCL I especially would like to thank my colleagues from ‘module VIII’. Pieter Fourie, for always providing thoughtful advice and showing the latest and best in software and statistics, Artem Chakirov for our many talks over coffee and across our desk, and Sergio Ordonez for his help with programming and the formulation of many ideas found in this thesis. From my colleagues at IVT in Switzerland I especially would like to thank Patrick Schirmer. I truly enjoyed our collaboration on residential location choice modelling, and the extensive discussions on both our PhD’s.

At SMART MIT I would like to thank Jingsi Shaw and Prof. Joe Ferreira,
and the collaboration on residential location choice in Singapore, which accumulated in the survey underlying several of the chapters in this thesis.

Finally, I would like to thank my family and friends. First my parents, who continuously encouraged me in my studies, their support to undertake this adventure, and their help in Singapore in the final months of this thesis. My sister Anja for her continuing efforts to stay in touch, and thinking of many events that I tend to forget. Bas Hoksbergen who helped me to keep my focus on the thesis, and the handing in of it. Most of all I would like to thank Lina for joining me on this journey to Singapore, her forgiveness for the many long days and late nights, and the joy that we experience every day with Milou and Otis.

Michael A.B. van Eggermond
Singapore, December 2017
Chapter 1

Introduction

1.1 Background

Cities have been the backbone of human civilization; they are the place where flows of people, goods, money and ideas meet. Given the complexity of interactions within cities, urban planning was always called for. The size, scope and scale of urban planning has varied over the centuries: whereas before 1800 urban interventions were mainly on the building level, urban planning has been conducted on a increasingly larger scale (Bettencourt, 2013). Cities built before the advent of large scale formal planning practised remain universally attractive to people today. This requires that the built environment of cities is able to change, in response to social and economic needs (Bettencourt, 2013).

One example of such responsiveness can be found in the interaction between transport and land-use. Hansen (1959) showed for Washington D.C. that locations with a good accessibility, defined as the access to employment and population, had a higher chance of being developed than remote locations. This recognition that trip and location decisions co-determine each other, and that transport and land-use planning need to be coordinated led to the term 'land-use transport feedback cycle' (e.g. Wegener and Fürst, 1999) (see also Figure 1.1). Summarizing, the land-use transport interaction cycle describes that the spatial separation between human activities, provided by different land-uses, creates the need for the transport of people and goods. In the feedback cycle a number of transport-related decisions are shown, starting with the choice to own a car, the decision to make a trip, the choice of destination and subsequently route choice. Route choice subsequently leads to link loads, and eventually congestion and crowding. These again influence the generalized cost of
Figure 1.1: Land-use transport interaction cycle


travelling, in Figure 1.1 defined as 'travel times, distances & costs'. Conversely, the transport system impacts the location decisions of investors, the choice whether to undertake construction and the subsequent decision to move by households and firms. The mediating factor between transport and land-use is accessibility and the resulting attractiveness of locations. Cities are the subsequent result of a series of cumulative decisions of many agencies and persons (Lynch, 1984).

In general terms, accessibility is a measurement of the spatial and temporal distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome this spatial separation (Hansen, 1959). While the concept of accessibility has been known since the 1950’s, it has only recently drawn attention from practitioners as one attractive indicator measuring the combined effects of transport policies and urban planning.
To describe the interaction between land-use and travel behaviour, accessibility measures are frequently included in travel behaviour studies. However, if accessibility measures are considered, they tend to be zonal and car-based measures (Handy and Clifton, 2001a). Walking, cycling and public transport are seen as modes that can reduce the negative externalities caused by the use of the automobile, such as congestion, particle emissions and noise emissions. A clear disparity exists between private and public transport accessibility (e.g. Levinson, 1998; Shen, 1998; Hess, 2005; Kawabata, 2009; Benenson et al., 2011; Salonen and Toivonen, 2013). These zonal accessibility measures can be considered regional accessibility measures: they measure the accessibility to jobs or population. While regional accessibility has implications for home-work travel, it might not characterize non-work travel sufficiently. Local accessibility describes the accessibility to nearby destinations, and is considered a measure describing the built environment. Other measures describing the built environment include density, diversity, design, and distance to transit (Ewing and Cervero, 2010). A built environment scoring well on these "D’s" influence the propensity to use active modes of transport (Ewing and Cervero, 2010).

More specifically, the proximity to stores, a high intersection density, the job/housing mix as well as the diversity of land-use tend to promote walking, confirming that the propensity to walk is related to both infrastructure and destinations. Given the relevance of the built environment, and that this environment is one of the outcomes the transport and land-use cycle, it is necessary to view the built environment as an integral part of the transport land-use feedback cycle.

The forces of the land-use transport feedback cycle, combined with the outcomes of urban and transport planning, influence the transport system as well as the separation of land-uses. Rybczynski (2011) provides two contrasting perspectives on urban planning. Architects and planners present solutions based on what they think ought to be: greener, more diverse, more lively, possibly within constraints provided by policy-makers and developers. Paradigms on what 'ought to be' have varied greatly; Ebenezers’ Garden City, and the Voisin scheme for Paris by Corbusier are only two example of how 'cities of tomorrow’ were viewed in the past (e.g. Hall, 2002).

The architect’s perspective stands in contrast to an economists’ view, which revolves around the question what people themselves actually
want. Common in micro-economics is to view an individual as a utility-maximizing rational agent; the standard model of micro-economics (e.g. Mas-Colell, 1995). Discrete choice models allow to capture the behaviour of individuals and households (e.g. McFadden, 1974; Train, 2003). Discrete choice models have gained tremendous popularity within quantitative transport modelling, judging by the number of studies applying discrete choice modelling. Within the discrete choice framework, a decision-maker chooses from a set of finite alternatives. Each alternative is assumed to have a number of attributes; each attribute has a level of utility or disutility, which capture the costs and benefits of an alternative. Within economics and psychology, a set of theories has emerged as a reaction to the assumptions underlying the utility maximization approach. Simon (1955) introduced the term 'bounded rationality' and asserted that individuals do not extensively evaluate all available alternatives; instead decision-makers search for information until they are satisfied and make a decision subsequently. Tversky (1972) discusses the heuristic elimination by aspects; the most important attribute is determined and a cut-off value is retrieved by the decision-maker. All alternatives with a value below that cut-off are eliminated. Prospect theory (Kahneman and Tversky, 1979) describes the decision-making process in two stages. In the first stage, alternatives are framed: a reference point is set against which alternatives are evaluated. In the second stage alternatives are evaluated against this reference point in terms of gains and losses. Discrete choice theory is commonly applied to evaluate travel-related decisions, such as mode choice, destination choice, but also to evaluate long-term choices such as the choice of residence and the choice of employment location.

The majority of the research is set in Singapore. Singapore is located just one degree north of the equator in Southeast Asia with a land area of 712 km², a permanent residential population of 3.77 million and a total population of 5.08 million in 2010, compared to respectively 697 km², 3.27 million and 4.03 million in 2000. GNI per capita amounts to US$ 54,580, 2013), which makes it one of the wealthiest countries in Asia. Singapore has witnessed tremendous growth since its independence in 1965; a key to economic growth in Singapore has been the formulation and execution of land-use and transportation policies in an integrated manner, with a long-term vision (e.g. Richmond; 2008; Huat; 2011).

Several of the finding are contrasted to Switzerland. Switzerland is a
landlocked country located between Western and Central Europe with a population of 8.2 million people (2013) The majority of the population lives on the Swiss Plateau, which covers 30% of its 41,285 km\(^2\) area. Approximately 75% of the populations lives in urbanized areas. Over the last decade, population and job growth mainly take place in urban agglomerations, in contrast to the growth mainly occurring in rural areas in the period from 1980 to 2000. Commuting between rural areas and cities is becoming more commonplace (Bundesamt für Raumentwicklung ARE, 2009).

1.2 Objectives & methods

1.2.1 Research objectives

The research objectives of this thesis are twofold. The first objective is to contribute to the measurement of the built environment and the relationship between the built environment and transport and land-use related decisions by individuals. After all, on one hand there exists the need to describe, measure and design the built environment; on the other hand there is the economist’s perspective, that takes interest in what individuals and households value when making choices.

The second objective is to provide insights in these factors for the city state of Singapore, given existing and newly generated data sets. Singapore has been selected as a study area as this research was conducted ‘in place’, due to the availability of relevant data, but also because Singapore, as a highly dense city, can provide additional insight into research domains that have been solely addressed in United States and Western Europe.

Two main topics have been selected from the transport land-use interaction cycle. The first topic is accessibility. Accessibility has been selected as it is where transport planning and urban planning meet, but also because it should be characterized differently when measured on the local scale and the regional scale. Accessibility will be contrasted to mode choice and the choice to own a vehicle. The second main topic is residential location choice. This topic has been addressed for several reasons. First, in the longer term there is the intention to extend the multi-agent transport demand model for Singapore with a land-use component (Erath et al., 2012). Second, residential location choice is one of the driving forces
of urban dynamics: household’s decisions where to live drives, among others, transportation flows and the demand for amenities. Given the lack of publicly available data sources an investigation of residential location choice in Singapore was necessary.

1.2.2 Research methods

The research presented in this thesis made use of a variety of research methods starting with reviews of literature; to obtain empirical insight and into methodologies employed literature reviews have been conducted.

To quantify accessibility, built environment and human behaviour a range of data sets has been used. Commonly, a distinction is made between actively collected data and passively collected data. In this context, actively collected data refers to data through dedicated surveys tailored to get insight in the specific research questions. Passively collected data refers to data collected in an automated manner, such as through automated fare payment systems or phone data. A second classification of data in the context of land-use and transport studies is the distinction between revealed preference and stated preference data. Revealed preference data typically takes the world as it is now, have only existing alternatives as observable and alternatives can only be described by attributes as currently exist (i.e. relationships between attributes are fixed). Stated preference data can describe existing or hypothetical contexts, with either existing alternatives or currently non-existing alternatives, and the relationship between attributes can be controlled (Louviere et al., 2000).

This thesis makes use of both actively collected data and passively collected data. Revealed preference data includes travel surveys from Singapore and Switzerland. In addition, a survey was developed to investigate residential mobility and location choice in Singapore based on recent moves of households. To depict the spatial structure of Singapore’s public transport smart card data has been used; a passively collected dataset.

Given that the topics addressed in this thesis are inherently of a spatial nature, spatial analysis has been applied. Fischer (2006) makes a distinction between spatial point and spatial interaction data on one hand, and exploratory, spatial data driven analysis and model-driven data analysis on the other hand. The analysis of accessibility both makes use of exploratory spatial methods for spatial point and spatial interaction data;
model-driven spatial analysis has been used for the estimation of distance decay parameters as well as residential location choice models.

Quantitative analysis commences with descriptive analysis; cross-tabulations, and graphs are used where appropriate. Behavioural models are estimated to obtain insight in the trade-offs individuals and households make.

1.3 Outline

To a large extent, the research presented takes Singapore as the area of study. Chapter 2 therefore continues with a more detailed background of transport and land-use policies in Singapore and concludes with additional research questions.

Chapter 3 provides an overview of the measurement of accessibility. It identifies, based on a literature review, several perspectives on the measurement of accessibility, continues with different accessibility measures and takes a closer look at the role of distance decay. To illustrate the role of distance and spatial structure on spatial interaction for Singapore as well for Switzerland, a set of distance decay functions are estimated and, as an illustration, applied to Switzerland.

Chapter 4 takes a closer look at the representation of the pedestrian network and resulting walking distances and the impact on pedestrian and transit accessibility to employment opportunities. Two types of pedestrian networks are considered: (1) a pedestrian network using road centrelines and (2) a pedestrian network derived from road centrelines, data sets indicating crossings and a set of rules. These networks are compared with accessibility to jobs if crow fly distance were considered.

Chapter 5 continues with the measurement of land-use and the interaction between transport and land-use on a finer level of granularity. It traces back the origins of the measurement of diversity in land-use to ecology, and provides a critique on the usage of diversity measures for the measurement of land-use mix. It continues with destination indices. Diversity measures and walkability indices for Singapore and Switzerland are presented.

Chapter 6 presents a vehicle ownership models for Switzerland and Singapore, and usage model for Switzerland. To characterize the urban environment, a distinction was made between micro-accessibility, and regional accessibility.
Chapter 7 reviews the literature on residential mobility and location choice. It lays the foundations for a newly developed residential mobility survey for Singapore.

Chapter 8 introduces the residential mobility survey for Singapore. It presents the questionnaire, continues with the survey execution and a descriptive analysis of survey results.

Chapter 9 continues with an analysis of the residential mobility survey and seeks to answer the question who moves house in Singapore.

Chapter 10 pays special attention to the choice set formation as described by survey respondents. Household’s search preferences are incorporated into a choice set generation algorithm, which is subsequently applied to transaction data.

Chapter 11 presents residential location choice for Singapore, with different choice sets. These choice sets are generated by taking into account households’ search preferences.

Chapter 12 concludes this thesis with a synthesis of the conducted research, and proposes directions for future research.

Several chapters of this thesis have been appeared as journal publications or have been published in conference proceedings; therefore, inevitably, some overlap between chapters will exist.
Chapter 2

Singapore

2.1 Introduction

Singapore became self-governing in 1959 after being under the colonial rule of the United Kingdom since 1819. After briefly being part of the Malaysian Federation, full independence came in 1965. In the 50 years since its independence, Singapore has witnessed tremendous economic growth. Singapore in 2010, has a land area of 712 km$^2$, a permanent residential population of 3.77 million and a total population of 5.08 million, compared to respectively 697 km$^2$, 3.27 million and 4.03 million in 2000. GNI per capita amounts to US$ 54,580 (2013), which makes it one of the wealthiest countries in Asia.

This chapter provides an overview of urban planning, housing and transport policies in Singapore and the main actors that are active in these sectors.

2.2 Urban planning

The foundations for Singapore’s land-use and transport policies were laid with the State and City Planning (SCP) project, conducted between 1967 and 1972 by the United Nations and consultants through the United Nations Development Plan (Abrams et al., 1980). The plan sets out the challenges expected for Singapore due to rapid population growth; whereas Singapore’s population in 1962 surmounted to 1.75 million, a population of 3.4 million was expected in 1982. This first study resulted in the 1971 Concept Plan (Figure 2.1). This concept plan called for a series of high density settlements around a central open area, to be constructed at a rate of approximately
15,000 dwellings pro annum. The accompanying transport plan called for a ring of expressways and a basic mass rapid transit railway system (Rimmer, 1986) connecting the high density settlements and the central business district, located in the historic precinct at the southern tip of Singapore.

A critical element in Singapore’s urban planning is the control of land ownership. During the 1960’s, Singapore’s experience was that private land ownership provided a hurdle to industrialization and public housing development (Han, 2005). Furthermore, land was seen as an important resource in the otherwise resource-scarce Singapore. The Land Acquisition Act of 1966 "conferred powers on the state to acquire land for any public purpose or for any work or undertaking which is of public benefit, public utility or public interest, or for any residential, commercial or industrial purpose" (Phang, 1996a). State ownership of land increased from 31% in 1949 to 80% in 1990 (Han, 2005). Almost 47% of this land had been acquired by the Housing Development Board, followed by 46% by the Land Office on behalf of the Singapore Land Authority. Both authorities will be
2.3. Housing

Two main institutions have shaped the Singaporean housing market: the Housing and Development Board (HDB) and the Central Provident Fund (CPF). HDB was set-up in 1960 to replace the Singapore Improvement Trust (SIT) as national housing provider, which failed to meet the housing

discussed later in this section.

Land-use planning is conducted by the Urban Redevelopment Authority, a statutory board under the Ministry of National Development (MND). The planning process consists of three elements: the Concept Plan, the Master Plan and the implementation of the Master Plan through government land sales and the control of development (URA, 2017b).

The Concept Plan is released approximately every 10 years and is a strategic transportation and land-use plan. The focus of the Concept Plan has shifted over the last decades. Whereas the focus of the first Concept Plan was on the earlier mentioned ring concept, mass rapid transit, high density new towns and the relocation of the population from the city centre to these new towns, the second Concept Plan focused on the development of four regional centres, the development of the Marina Bay area in the downtown area, the construction of expressways and the development of more recreational facilities. The third concept plan, released in 2001, focused on Singapore’s position as a world-class city (Han, 2005). The most recent Concept Plan was released in 2011. This plan sets out to create a "high quality living environment for a possible population range of 6.5 to 6.9 million by 2030" (URA, 2016). It focuses on affordable housing, especially mentions walking and cycling as increasingly important modes of transport and envisages Singapore as a city in a garden.

The second main planning tool is the Master Plan; a statutory plan that translates the strategies outlined in the Concept Plans into detailed plans, and specifies the land-use type, allowed plot ratio and densities for land plots. It is revised every 5 years. In the Master Plan, a distinction is made between 5 planning regions, divided into 55 planning areas and over 300 subzones. Any development in Singapore is subject to development control: a written permission is required before any development or subdivision of land can be carried out (Han, 2005).
demands of the growing population. Whereas the SIT built an estimated 20,907 units in the post-war period between 1947 and 1959, HDB planned to built 110,000 units between 1960 and 1970 (Phang, 2007).

In 1964, the Home Ownership Scheme (HOS) was introduced by the Singapore government, and HDB began offering housing units for sale below market prices on a 99-year leasehold basis. HDB is able to price its units below market prices because the flats are built on state owned land, a result of Singaporean land policies. State land is made available for public housing, industrial estates and other public projects (Phang, 1996b).

As outlined in the 1971 Concept Plan, housing was to be located in new towns in a ring around the central reservoir. Eng (1986) highlights a series of design principles underlying these new towns. First, due to land scarcity, the far majority of the residents of new towns should be housed in high-rise, high density flats. Second, new towns were largely self-contained: basic community and shopping facilities should be provided in a neighbourhood centre. Each neighbourhood was to have approximately 4,000 to 6,000 dwelling units, and accommodate 20,000 to 30,000 people. A new town consists of several of neighbourhoods, and has between 25,000 and 50,000 dwelling units, housing a population between 125,000 and 250,000. Office employment was never planned for in a new town, but initially they did contain ‘clean labour intensive‘ industry. Finally, given the scarcity of land, in contrast to new towns developed in post-war Europe, the Singaporean new towns were characterized by expressways, major avenues or other physical barriers.

From 1968 onwards, it became possible for Singapore citizens to make pre-retirement withdrawals from their mandatory retirement savings, the Central Provident Fund (CPF), to pay for the down payment, mortgage and other transaction costs of purchasing an HDB flat (Chua, 2014). The HDB resale market was established in 1971; prior to 1971, HDB owners had to return their flat to HDB at the purchase price. Since 1973, HDB owners have to occupy their flats for five years before being allowed to resale the flat. Singaporeans are eligible for certain housing grants when buying an HDB resale flat. Examples include first-time applicants, families buying a flat close to their parents and first-time single applicants aged 35 and over.

HDB primarily catered for low- and middle-income families. To provide housing for higher income households, Executive Condominiums were introduced in 1996. Applicants have to satisfy certain eligibility criteria
and face restrictions regarding the resale of their flat during the first 10 years of ownership.

Until the early 2000’s, HDB built based on estimates and not on actual demand. This ensured a relatively short waiting queue for prospective homeowners. However, in 2002 HDB was faced with an oversupply of 17,500 flats and no prospect of selling these flats (Chua, 2014). Construction of new flats was suspended, and HDB changed its construction policy: instead of constructing ahead of demand, construction only begins when at least 70% of the flats of the proposed site are sold. In 2002 this Build-To-Order (BTO) system was fully implemented and replaced the existing Registration for Flats system (RFS). BTO is one of two ways in which HDB sells new flats; the other method is dubbed Sales of Balance Flats (SBF).

Under the BTO scheme, prospective home-owners ballot for a flat in proposed sites. Applicants receive a queue position; based on the queue position, applicants participate in a booking exercise where they can select their preferred block and flat. The queue position is based on a number of factors, for instance whether applicants participate in a ballot for the
first time or whether applicants plan to buy a flat for the first time. After selecting a flat, applicants are required to make a down payment. The number of applications varies markedly. Proposed sites close to the city centre and in mature HDB towns are generally popular, whereas proposed sites in new towns receive fewer applications. HDB maintains a number of eligibility conditions for applicants for HDB new sale flats. Applicants have to be Singapore citizens, engaged, at least 21 years old, set within the income ceiling of the flat they intend to buy and not own any property in Singapore or overseas. Since 2013, a limited number of two-rooms flats are set aside for singles aged 35 or over in BTO ballot exercises (Chang, 2013). In 2015, HDB has built over a million units located in 23 HDB towns and three estates (HDB, 2016b). Figure 2.2 highlights the locations of these HDB towns; Figure 2.4 shows the locations of BTO blocks constructed since 2002.

Condominiums were introduced in Singapore in 1974. The high-rise and high-density nature of condominiums has become a key planning strategy
Figure 2.4: HDB Build-to-Order blocks and number of units since 2002

Source: Compiled by author

to optimize land scarce resources in Singapore (Sing, 2001); condominiums are mostly built on land obtained in government land sales on a 99-year leasehold basis. Condominiums are often better designed and possess a higher building quality than HDB flats. Furthermore, they are equipped with a full range of recreational facilities, such as gyms, swimming pools and barbecue pits.

Figure 2.6 summarizes the different residential segments and actors active in the residential market of Singapore; Table 2.1 provides an overview of the number of units per dwelling type. The dominant sector in the residential market is the owner-occupied public housing sector; the HDB provides approximately 80% of the housing stock, of 95% is owner-occupied (HDB, 2016b). HDB flats can be purchased as new sale Built to Order or Sale of Balance) by Singaporeans meeting certain eligibility requirements; HDB
flats can also be bought as resale flats by Singapore citizen and permanent residents. Prices for resale flats are determined by market forces, but HDB sets certain eligibility criteria.

In addition to selling flats, HDB also rents out flats. The public housing rental sector can be seen as the *de facto* social housing sector of Singapore. Gross monthly household income cannot exceed S$1,500 and households must meet certain criteria regarding household composition. HDB owners are allowed to sublet a room of their flat after having obtained permission from HDB. Singaporeans not residing in Singapore, but owning an HDB flat, can obtain permission to sublet their entire flat.

The owner-occupied private sector caters mainly to Singaporeans, permanent residents, expatriates and foreign investors. Land for private housing is available on freehold, 999-year leasehold and 99-year leasehold basis. Within the private sector, a distinction can be made between landed property (i.e. family houses in the main), apartments and the condominiums mentioned earlier.
The private rental sector caters mainly to expatriates. There is no rent control in Singapore; prices are fully determined by the market.

There are two financing systems in place in Singapore: the HDB public financing system and the commercial finance sector. HDB provides subsidized mortgages to eligible households. Currently, HDB grants subsidized loans to first-time home buyers and second-time home buyers to upgrade their HDB flat. Private and public home-owners have to obtain a loan from private banks and other financial institutions (Neo et al., 2003). Singaporeans can withdraw funds from their CPF savings for the down payment and mortgage instalments for both HDB and private property.

2.4 Land transport

Singapore’s progressive motorization policies and stringent land-use planning has received attention in several reviews (e.g. Rimmer, 1986; Willoughby, 2001; Barter, 2008; Richmond, 2008). The 1971 Concept Plan had a large
Table 2.1: Number of dwelling units in the Singaporean housing market

<table>
<thead>
<tr>
<th></th>
<th>Owner-occupied</th>
<th>HDB Rental</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HDB [units]</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Room</td>
<td>255</td>
<td>25,543</td>
<td>25,798</td>
</tr>
<tr>
<td>2-Room</td>
<td>11,995</td>
<td>25,905</td>
<td>37,900</td>
</tr>
<tr>
<td>3-Room</td>
<td>226,972</td>
<td>1,674</td>
<td>228,646</td>
</tr>
<tr>
<td>4-Room</td>
<td>379,687</td>
<td>266</td>
<td>379,953</td>
</tr>
<tr>
<td>5-Room</td>
<td>224,402</td>
<td></td>
<td>224,402</td>
</tr>
<tr>
<td>Executive condominium</td>
<td>65,079</td>
<td></td>
<td>65,079</td>
</tr>
<tr>
<td>Studio apartment</td>
<td>7,078</td>
<td></td>
<td>7,078</td>
</tr>
<tr>
<td>Total HDB</td>
<td>915,468</td>
<td>53,388</td>
<td>968,856</td>
</tr>
<tr>
<td>Of which whole flat subletted</td>
<td>48,338</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Private market [units]</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apartments</td>
<td></td>
<td></td>
<td>84,997</td>
</tr>
<tr>
<td>Condominiums</td>
<td></td>
<td></td>
<td>170,459</td>
</tr>
<tr>
<td>Detached House</td>
<td></td>
<td></td>
<td>10,738</td>
</tr>
<tr>
<td>Semi-Detached House</td>
<td></td>
<td></td>
<td>21,914</td>
</tr>
<tr>
<td>Terrace House</td>
<td></td>
<td></td>
<td>39,340</td>
</tr>
</tbody>
</table>

Sources
* HDB Annual report 2014/2015
** URA REALIS, 2015 Q4

influence on a series of transport policies: (1) the choice to pursue a transit-oriented and compact urban structure, (2) a restraint on private vehicle ownership and usage, and (3) the commitment to improve public transport (Barter, 2008).

A set of policies has been put in place to curb vehicle ownership and usage. First, a set of policies has been devised to decrease the attractiveness of purchasing a car by increasing the up-front costs. Vehicle growth was capped at 3% under the Vehicle Quota System (VQS) until mid 2011 and was decreased since then. In addition to the open market value (OMV) of the vehicle, a registration fee (S$140), an additional registration fee (ARF) of 100% the OMV, an excise duty of 20% of the OMV and a 7% Goods and Services Tax has to be paid. Furthermore, the prospective car owner has to bid for a Certificate of Entitlement (COE) under the VQS with a validity of 10 years and pay for an annual road tax based on the engine capacity (Li et al., 2011). Second, the usage of car is being discouraged
initially by the Area Licensing Scheme (Rimmer, 1986) and later by tolling road users through Electronic Road Pricing (ERP). The current scheme has different charges according to vehicle type, time of the day, and location of the gantry (Santos et al., 2004). Small changes in ERP rates have been effective in controlling demand and prove to provide a high degree of control (Richmond, 2008). Nevertheless, ERP gantries have been positioned closer to residential areas in recent years to control congestion. Over the years, VQS has been more controversial than ERP; COE rates have reached a level that they restrict car ownership by a large part of the population (Richmond, 2008).

Fast-forwarding to 2015, an extensive system of rail-based transport has been constructed, supplemented by bus-services. As laid out in the aforementioned concept plans Singapore’s urban structure is closely tied to the mass rapid transit (MRT) system. The plan for a strong concentration of office space was a decisive factor to develop a MRT system over a bus-based system; additionally, bus rapid transport (BRT) was not demonstrated to be a successful technology at the time moment the decision for the MRT was made (Barter, 2008). Singapore’s public transport card was introduced in April 2002; smart cards can be used island-wide for payment of all modes of public transport, regardless of operator. Though cash payment of single fares at higher rates is still possible, e-payments using smart cards account for 96% of all trips (Prakasam, 2008). Smart card data records include the boarding station, boarding time, end station and time.

Notwithstanding, public transport operators have not pushed towards customer-oriented, highly integrated public transport planning; it can be that due the ownership and usage restraints have let public transport operators to assume that their riders are captive riders (Barter, 2008). LTA has set out on a reform of the bus reform to make public transport operators more competitive and has restructured the ownership of public transport vehicles. Nevertheless, bus route reform is not embarked upon yet.

A consequence of the strong focus of transport planning on public and private transport planning is that active modes of transport are not well catered for. There is (was) a marked lack of attention to planning for bicycles as a mode of transport, other than as a mode for sporadic leisure cycling (Barter, 2008). Outside of the Central Business District, urban form is dictated by relatively large blocks, long traffic light cycle times and roads with few crossing opportunities for pedestrians. Again, LTA and URA have
realized the necessity to improve accessibility by active transport and have commenced with the planning and construction of bicycle lanes, and the construction of sheltered walkways to protect pedestrians in public housing estates from tropical weather.

2.5 Conclusions & implications for research

Since it’s independence, Singapore has developed itself into a First World nation, to large extent due the active role of the government that has implemented long-term urban plans and a large-scale national housing plan (Huat, 2011). This chapter has discussed the urban planning, housing and the land transport system of Singapore as these topics will be of relevance for the remainder of this thesis.

The 1971 Strategic Concept Plan has been guiding in the developmental vision of Singapore. This plan called for a series of high density settlements, connected by mass rapid transit to a central business district. Housing in these settlements, public housing, was provided by the housing development board (HDB). The next chapter will look at travel times by trip purpose as a result of stringent urban planning and compare this to travel times by trip purpose in Switzerland, as a counter-example of a country where less planning interventions took place.

A second topic of interest concerns the implications of the prioritization of motorized transport over non-motorized transport in the development of infrastructure. This prioritization warrants a closer look at the impacts of considering pedestrian networks for non-motorized transport in the calculation of accessibility. This analysis will be presented in Chapter 4.

The fact that over 80% of the housing stock is provided for by HDB, of which 95% is owner-occupied, makes that an investigation looking into residential location choice needs to take into account HDB. Second, given the clearly demarcated segments within HDB, including the differentiation between HDB New sale, HDB resale, and HDB rental. These aspects, combined with findings from other studies concerning residential location choice, will need to be taken account when researching residential location choice in Singapore.
Chapter 3

Accessibility & spatial structure

3.1 Introduction

Increasingly, planners are exploring alternative measures to evaluate the outcomes of policies and plans. Whereas transport planners have long focused on improving connectivity and increasing mobility, it has become clear that improving access to desired opportunities, including employment, leisure and social, should be key to a successful land-use and transport policy.

The access to opportunities, better known as accessibility, is determined by the spatial arrangement of opportunities and the ease of reaching these opportunities. Accessibility contains a land-use and transport component and describes the outcomes of urban and transport planning simultaneously. On one hand, accessibility can be increased by increasing the number and variety of destinations. Conversely, decreasing the travel cost to reach these opportunities improves accessibility.

Several contrasting perspectives on accessibility exist. One of these perspectives is the differentiation between local and regional accessibility (Handy, 1993). Regional accessibility is commonly measured as the accessibility to jobs or population from a community or neighbourhood. Areas such as these might be operationalized as traffic analysis zones, or planning areas. While regional accessibility has implications for work travel, it might not characterize non-work travel sufficiently. Local accessibility describes the accessibility to activities within a community, neighbourhood or zone; these activities can include activities other than work, such as
shopping or leisure. The distinction between regional and local accessibility can be seen to originate in the data available to compute these measures (e.g. jobs, travel times). Traditionally, zonal travel times as well as zonal statistics have been used to compute accessibility to jobs. Recent advances have made it possible to calculate accessibility for large metropolitan areas on a fine grained level, thus blurring the line between regional and local accessibility.

Several other contrasting perspectives in accessibility can be recognized in literature, including people versus place-based accessibility, normative versus positive accessibility and potential versus actual accessibility (e.g. Niedzielski and Eric Boschmann, 2014). These perspectives will be discussed in section 3.2.

An integral part of accessibility is distance, or more general, the ease of reaching opportunities. As Tobler’s first law of geography states everything is related to everything else, but near things are more related than distant things (Tobler, 1970). This deterrence to distance is captured with distance decay functions, often referred to as impedance functions. A wide range of functions can be found in the literature, as well as discussions whether these functions capture spatial structure or actual travel time preferences.

This chapter and the subsequent two chapters look closer at the measurement of accessibility. This chapter continues with the measurement of accessibility, common accessibility measures, distance decay functions and the role of spatial structure. While most of the concepts presented in this chapter are generally used for the measurement of regional accessibility, these also hold for the measurement of local accessibility.

This chapter makes use of several data sources: the Singaporean and Swiss household interview travel survey are used as a basis of the analysis of travel times. Additionally, public transport smart card data is available for Singapore, and publicly available job data from Switzerland and estimated jobs in Singapore are used.

Chapter 4 will continue with the measurement of pedestrian and transit accessibility, and looks at the outcome of accessibility when taking into account the pedestrian network, thus linking the local, micro level with the regional, macro, level. Chapter 5 continues with the measurement of accessibility on the micro level, taking into account destinations other than work, and evaluating other indices than just accessibility.
3.2 Measuring accessibility

Accessibility has long been a topic of interest in planning, transportation research and geography. As such, several definitions of accessibility can be found in the literature. Commonly, it is defined as the measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome this spatial separation or ‘the potential of opportunities of interaction’ \citep{Hansen1959} or ‘the freedom of individuals to decide whether or not to participate in different activities’ \citep{Burns1979}. In its most simple form, accessibility takes into account two elements: a surface of relevant destinations and the characteristics of a transport network linking these points \citep{Vickerman1974}. \citet{Burns1979} extends this abstract notion and explicitly links the individual to constraints that limit the individual freedom to access destinations: transportation, temporal and spatial constraints. \citet{Geurs2004} further summarizes these four components that are relevant when measuring accessibility: (1) a land-use component, consisting of the amount, quality and distribution of opportunities as well as the demand for these opportunities (2) a transportation component, expressed as the disutility to cover the distance between an origin and destination, ideally for different modes and accounting for different travel time components, (3) a temporal component referring to the availability of opportunities by time of day and the availability of an individual to partake in these activities, and (4) an individual component.

3.2.1 Perspectives on accessibility

*Place-based and person-based accessibility*

A first contrasting perspective on accessibility can be found in the notions place-based and person-based accessibility. The concept of place has been central in the measurement of accessibility; places provide ordering to geographic space and offer the possibility for people to perform activities. The accessibility of a location is measured by its potential interaction with other locations. Conventional place-based accessibility aggregated and simplified places to arbitrary, geographic boundaries, such as traffic zones or census tracts: accessibility becomes a property of geographical areas instead of accessibility experienced by households or individuals.
Zonal-based accessibility measures have drawbacks. The first drawback can be found in the usage of zones to represent boundaries. Zonal schemes may not correspond to individuals’ perceptions of the geographic and temporal availability of urban opportunities (Kwan and Weber, 2003). Instead, as people interact with the built environment, they interpret and encode this environment into mental maps. According to Lynch (Lynch, 1960), this environment includes landmarks, routes, nodes, edges and zones. For instance, Banerjee and Baer (1984, p.108), found that maps drawn by low-income minorities in Los Angeles were much more constrained in area and density of details than higher-income white residents. Eng (1994) conclude that transient residents in Singapore residing in private housing display a limited awareness as compared to the long-term residents residing in public housing.

A second drawback is given by the modifiable areal unit problem (MAUP) and ecological fallacy (Kwan, 1998). Zones of varying sizes and configurations will yield different relationships between accessibility and other characteristics (Kwan and Weber, 2003). The MAUP problem could be circumvented by zooming to very low levels of spatial and temporal resolution, by breaking up zones into different types of activities on a very high spatial resolution. Recent applications have shown that computational issues can be overcome when zooming into a high level of spatial and temporal detail; however, whether data is available on this level of detail remains questionable.

A place-based perspective stands in contrast to the people-based perspective of accessibility. Instead of using places as surrogate for people and their activities, a people-based approach focuses directly on individuals’ activities, and their use of places in both the real and virtual world (Miller, 2007). This time-geographic perspective is based on the notions of space-time paths, capability constraints, coupling constraints and authority constraints (Hägerstrand, 1970).

**Normative and positive accessibility**

A second contrasting perspective was presented by making a distinction between normative and positive accessibility (Páez et al., 2012). By taking on one hand the cost of travel and on the other hand the distribution of opportunities, they provide a normative and positive implementation of both these components. On one end of the spectrum both costs of travel and the distribution of opportunities can be implemented as normative measures:
accessibility is then measured by desired / assumed location of firms or services and the desired / assumed location of firms. On the other end of spectrum there is the positive implementation: accessibility is based on the actual / observed location of firms and the actual behaviour of travellers. Páez et al. (2012) criticize normative accessibility measures as norms tend to be derived from values derived in literature, but not correspond to actual travel behaviour and/or preferences.

An example of a normative accessibility measure is a policy measure describing the proximity to child care: for instance, every resident should have a child care within 1km of their residence. Deviation from this norm might prompt policy intervention. 

**Potential and actual accessibility**

A final contrasting perspective can be found in the notions potential and actual accessibility. Whereas positive accessibility measures use travel behaviour indirectly, actual accessibility measure use observed travel directly by incorporating actual travel distances and times, and the deterrence to distance. Thus, they provide an indication what accessibility is, instead of measuring what it could be (potential) (Niedzielski and Eric Boschmann, 2014).

Potential model accessibility measure on other hand a set of opportunities (e.g. jobs, population), and measure the accessibility from a series of origins to these opportunities, and incorporate travel costs. As such, they represent the potential to reach places, but lack a reference to actual travel behaviour. Given the increasing availability of data and computation power, potential accessibility measures are increasingly popular.

### 3.2.2 Accessibility measures

Regardless of the perspective on accessibility it is necessary to define measurements of accessibility.

The simplest of accessibility measures, the cumulative opportunities measures, sums up all opportunities within a specified travel time or distance band. More complex accessibility measures have been developed, including accessibility measures derived from the gravity model, measures incorporating random utility theory and time-space measures.

The first two types of accessibility measures are calculated by multiplying the attractiveness of a destination by a generalized cost function:
Chapter 3. Accessibility & spatial structure

\[ A_i = \sum_{j=1}^{n} d_j f(c_{ij}) \]  

(3.1)

where \( A_i \) is the total accessibility of origin \( i \), \( d_j \) are the opportunities at destination \( j \), \( f(c_{ij}) \) is the impedance function.

The simplest accessibility measure, the cumulative opportunities index, is obtained by assuming a rectangular impedance function. This function takes a value of 1 when the costs are below a certain threshold, and 0 when the costs are above this threshold. This measure counts the number of opportunities within given travel costs. Among others, this measure is popular because of its ease of interpretation and calculation. A variant on this type assumes a linear impedance function.

The gravity model weights opportunities according to the impedance function; over the course of the last decades, a range of impedance functions has been proposed. This will be addressed in the next section.

Utility-based measures are based on random utility theory. It is assumed that an individual assigns utility to each destination, the travel time and mode for reaching each destination in their choice set. The logsum, as a measure of accessibility, is then defined as (e.g., Niemeier, 1997):

\[ A_n = \ln(\sum_{\forall k \in C} e^{V_{nk}}) \]  

(3.2)

The final group of accessibility measures comprises of time-space measures. These are founded in the space-time geography of Hägerstrand (1970). He proposes to represent accessibility as a three-dimensional prism of the space and time available to an individual for partaking in activities. The motivation behind this approach to accessibility is that individuals have only limited time periods during which to undertake activities. As travel times increase, the size of their prisms shrink. Hägerstrand (1970) identifies three constraints on individuals’ activities in space. Capability constraints limit the individual’s activities through the tools and resources of the individual, and the individual’s physical capabilities. Examples include the necessity to sleep for a number of hours or whether an individual
possesses a driving license and private vehicle. Coupling constraints define how long an individual has to join other individuals in shared activities. The third set of constraints are authority constraints, indicating constraints defined by a space-time domain. Examples include temporary constraints, such as a seat in a theatre; other constraints are more fixed and have a strong legal status, such as the premises of a firm or neighbourhood. Hägerstrand (1970) makes a further distinction between fixed and fluid activities. Fixed activities are activities that cannot be rescheduled or relocated; flexible activities can be more easily rescheduled, or can take place at more locations (Miller, 2007). Miller (2007) points out several weaknesses of classic space-time geography, including the focus on physical movement and presence. While classic time geography accounts for the telephone, accounting for the access to communication and the potential to virtual interaction is of importance. He points to the necessity of more research in an era of mobility and connectivity.

3.2.3 Distance-decay

*Impedance functions*

A large number of studies has set out to quantify the relationship between spatial interaction. The ’standard’ gravity model assumes a cost function based on an exponential function. In the 1970s and 1980s a range of further distance decay functions has been proposed. Taylor (1971) focused on the transformation of distance in decay functions and applied a range of distance transformations and showed several decay functions: a normal, exponential, square root exponential, log-normal and pareto distribution, similar to Ingram (1971) who evaluated a reciprocal function, the negative exponential function and a gaussian function. Martínez and Viegas (2013) proposed a new way to model distance-decay relationships, include psychological perceptions of ’close’ and ’far’. Additionally, they propose a new theoretical impedance function that is able to fit their empirical data better, especially for shorter distances. Redmond and Mokhtarian (2001) look into desired and actual commute time; they state that commute time is not a disutility that is minimized, but rather that there is an optimum that commuters aim to achieve. In their sample they find that commuters desire to travel 15 minutes and do not aim to live closer to their work location.

Table 3.1 shows a range of distance decay functions that can be found
Table 3.1: Frequently used distance decay functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>( f(c_{ij}) = \begin{cases} 1 &amp; \text{if } c_{ij} \leq C \ 0 &amp; \text{if } c_{ij} &gt; C \end{cases} )</td>
</tr>
<tr>
<td>Exponential</td>
<td>( f(c_{ij}) = \exp(-\beta c_{ij}) )</td>
</tr>
<tr>
<td>Power</td>
<td>( f(c_{ij}) = c_{ij}^{-n} )</td>
</tr>
<tr>
<td>Gaussian</td>
<td>( f(c_{ij}) = \exp\left(\frac{c_{ij}}{\nu}\right) )</td>
</tr>
<tr>
<td>Cumulative Gaussian</td>
<td>( f(c_{ij}) = \begin{cases} 1, &amp; \text{if } c_{ij} \leq C \ \exp\left(\frac{c_{ij}-C}{\nu}\right), &amp; \text{if } c_{ij} &gt; C \end{cases} )</td>
</tr>
<tr>
<td>Logistic</td>
<td>( f(c_{ij}) = \frac{1}{s} \exp\left(\frac{c_{ij}-m}{s}\right) \left(1 + \exp\left(\frac{c_{ij}-m}{s}\right)^{-2}\right) )</td>
</tr>
<tr>
<td>Log-normal</td>
<td>( f(c_{ij}) = \frac{1}{c_{ij}\sigma \sqrt{2\pi}} \exp\left(-\frac{(\ln c_{ij} - \mu)^2}{2\sigma^2}\right) )</td>
</tr>
</tbody>
</table>

in literature. The exponential and the power distribution are continuously decreasing monotonous functions, reflecting the assumption that there always is a deterrent to travel. The rectangular and cumulative gaussian function on other hand assume that there is indifference to travel up to a certain travel time or distance. The remaining distance decay functions are characterized by the possibility to capture a desire to travel and a deterrence to travel.

Despite the relevance of the distance decay function on the outcome of accessibility calculations, an evaluation of accessibility measures by trip purpose and mode are lacking. Notable exceptions can be found in work of Iacono et al. (2008) and Martínez and Viegas (2013).

Distance-decay and spatial structure

Traditionally, when a distance decay function is estimated, the results are interpreted as a behavioral measure of the relationship between distance and interactions. A sharply declining distance decay function indicates that the distance is perceived as a strong deterrent. A contrasting perspective on distance decay functions has been proposed: distance decay parameter estimates are a function of spatial structure as well as the result of behavior; spatial structure is defined as the size and configuration of origins and destinations in a spatial system (Fortheringham, 1981). On one hand, distance decay can exhibit directional variety. When distance decay param-
eters, are estimated, the rate at which interaction decreases over distance is similar in all directions. Distance decay however might be anisotropic instead of isotropic. Directional variation in distance decay can occur for a number of reasons: the presence of physical barriers, directional variety in religious, ethnic and social groups; and differences in transportation or communication availability (Fotheringham and Pitts, 1995). Fotheringham and Pitts (1995) investigated the possible directional variability in a migration model for the United States using Casetti’s expansion method (Casetti, 1972). With these models, the independent variables are interacted with the coordinates of the location of the observation. On other hand, distance decay can exhibit locational variety. Paez et al. (2010) also employed Casetta’s expansion method to determine travel time thresholds, which are location and person specific.

**Distance, time and spatial interaction**

Commonly, distance decay functions were estimated with the spatial interaction as dependent variable, where the spatial interaction is expressed as the percentage of flow between two locales (e.g. traffic analysis zones, municipalities, provinces, countries) as compared to the total outgoing flow. Given the orgins of the distance decay in geography, the spatial interaction between locales were obtained from migration statistics or other aggregate data sources (e.g. marriage distances), where locales can be large enough to be able to have sufficient observations of migration between each locale. The distance between two locales is used as an independent variable. Combined with the parameters required for the chosen distance decay function a curve can be estimated that describes the flow between locales. Instead of using the flow between zones it is possible to use the number of trips per distance, time or generalized cost bin as the dependent variable in the distribution. By assigning each observation to a bin and summing up the number observations per bin, a distance or travel time distribution is obtained. The advantage of this approach is that it is not necessary to observe the flows between locales, but that distributions can be estimated from travel surveys. Ortúzar and Willumsen (2011, p.184) highlight this approach; Iacono et al. (2008) estimate a wide range of exponential distance decay functions for different modes and different purposes employing this method. The estimated distance decay functions clearly differ per purpose and mode, which highlights the relevance of different decay functions.

Given the increasing prevalence of large datasets describing individual
movements, such as public transport smart card data and call detail records, it becomes possible to determine spatial interactions between locales on an intra-urban level. Whereas Simini et al. (2012) proposed a radiation model for human migration on a large scale (i.e. United States), Yan et al. (2014), Liang et al. (2013) attempted to understand the relationship between population density and distance to urban centre.

3.3 Travel times & trip distances

In this section a series of trip distributions for Switzerland and Singapore by trip purpose and mode derived from household interview travel surveys is presented. To additionally illustrate the spatial structure of Singapore a set of maps has been created based on public transport smart card. This section concludes with distance decay functions based on probability density functions for different trip purposes and modes.

3.3.1 Home-work trips: Singapore

To investigate the trip distance distributions for Singapore use is made of two separate data sources. The first data source is the Household Interview Travel Survey (HITS) 2012. For this survey over 32,000 persons from over 9,000 households have reported their travel behaviour on a single workday. The survey is conducted once every four years and is commissioned by the Singaporean Land Transport Authority (LTA). HITS contains data on three levels of aggregation. The highest level of aggregation contains household characteristics. Second, person characteristics are available such as age, income, profession and employment type. Third, information on trips and trip stages is available such as mode, purpose, cost and time. Travel time is derived from the trip start time and the trip end time, and thus includes, dependent on the mode of transport, access and egress walking time, waiting time and in vehicle time.

The second data source available are public transport smart card records. To extract home-work trips from this data source, the activity detection method developed by Chakirov and Erath (2012) was applied to the data. For the analysis presented in this chapter, the records from one weekday in 2013. This data set includes over 3.4 million trips on a single day. While this data set does not include modes other than public transport, it can be
seen as a full sample of public transport use, given the high penetration of public transport smart cards. It should be noted that travel times from public transport smart card data do not include access and egress time as well as the initial waiting time for the first vehicle used, but do include transfer time.

Figure 3.1a shows the home work travel time distribution for Singapore based derived from smart card records. Most trips are between 15 and 45 minutes; after 45 minutes a sharp decline in travel time can be observed. As a comparison the travel times per mode reported in the Singaporean household interview travel survey (HITS) are shown in Figure 3.1b. The reported travel times include walking and waiting time for trips made by public transport. While the shape of distribution is similar to the travel time distribution extracted from smart card data, the distribution is moved to the right as expected. The far majority of home-work trips is longer than 15 minutes. Trips conducted by private transport reveal shorter travel times than trips conducted by public transport. Private transport trips peak between 15 and 30 minutes. When compared to home-work trips as observed in public transport smart card data, public transport trips reported in HITS are longer.

3.3.2 Travel times & distances in Switzerland

A similar analysis has been performed Switzerland using the household interview travel survey called 'Mikrozensus' (Bundesamt für Statistik BFS, and Bundesamt für Raumplanung ARE, 2012). In this travel behaviour survey 59,971 households and 62,868 persons were surveyed on topics ranging from ownership of vehicles, driving licenses and public transport subscriptions as well on vehicle usage and daily travel behaviour. For each household member demographics such as age and driving license ownership are available. Dependent on household size, one or two household members above 6 years old are interviewed on their travel behaviour of a single day.

Given the possible difference between travel times and distances of trips originating in urban and rural areas, and differences in spatial structure between these areas, a distinction has been made by population size; as such, a place-based perspective on accessibility has been chosen to illustrate the different travel times distributions. Other classifications were imaginable, such as breakdown by population and/or employment density.
In addition to the modes walking, public transport and private transport, as shown for Singapore, two further modes of travel have been included in the analysis for Switzerland. First, the mode bicycle has been included as this mode has a significant market share, especially for shorter trips. Following the classification of public transport in the MZMV a distinction has been mad between local public transport and long distance public transport. Local public transport includes buses and trams; the mode public transport includes long distance trains.

Figure 3.2 shows the reported travel times for home-work trips by municipality size. The majority of the trips in small municipalities take up to 20 minutes. In municipalities with more than 50,000 inhabitants, travel times increase, as does the mode share for the modes walking and local public transport. Most bicycle commutes are shorter than 20 minutes, as are commutes by foot. A complementary analysis can be found in Figure A.1, where the trip distance distributions are shown. Not surprisingly, longer home-based work trips can be found in smaller municipalities. The market share for trips starting in larger municipalities by both local and
3.3. Travel times & trip distances

Figure 3.2: Travel time distributions of home-based work trips by population in Switzerland

long distance public transport is higher. Trip distance distribution by municipality size and mode are presented in Figure A.2. In this analysis the bin size has been reduced to 500 meters and trips above 12 kilometres are excluded. Municipalities with more than 100,000 inhabitants show the largest number of trips conducted within short distances; the far majority of these trips are conducted by foot. Municipalities with up to 10,000...
inhabitants reveal longer trip distances for home-based shop trips; these trips are mainly conducted by private transport.

Overall, the analysis of travel times versus trip distances reveals that travel times for respondents residing in smaller municipalities is lower than respondents residing in larger municipalities. Nevertheless, trip distances are longer in smaller municipalities. Travel time reductions are mainly the result of the usage of car transport over walking and public transport.

### 3.4 Estimated distance decay functions

The analyses and estimations presented in this section were performed with the statistical software \texttt{R} (\cite{RCoreTeam2013}) and the package \texttt{fitdistrplus} (\cite{Delignette-Muller2015}). In this section a series of distance decay functions are presented for different trip purposes and by different modes for both Singapore and Switzerland. In all cases, graphs are presented with the following: (1) a histogram density function with travel times grouped in 10 minutes intervals, (2) an empirical density function and (3) exponential, gamma, log normal and logistic density functions. To evaluate the goodness-of-fit of the estimated functions the likelihood as well as Akaike Information Critirium (AIC) is used. The parameters for the estimated distance decay functions are included in Appendix A.

#### 3.4.1 Estimated distance decay functions: Singapore

The estimated distance decay functions for home-work trips by private transport, and by foot and public transport in Singapore are presented in Figure 3.3a and 3.3b. As could be recognized in the trip distributions presented earlier, the empirical density function reveal significant commuting times of over 30 minutes for trips by private transport and 60 minutes for trips by public transport. Travel times by private transport trips are best captured by the logistic distribution; travel times by public transport are best captured by the gamma function.

Distance decay functions for home-based leisure trips are presented in Figure 3.3c and Figure 3.3d. For Singapore, it was chosen to include the trip purpose ‘shop’ under the nominator ‘leisure’. Again, a difference can be observed in the travel times for trips made by public transport and private
3.4. Estimated distance decay functions

Figure 3.3: Estimated distance decay functions for Singapore

(a) Home-work trips, private transport

(b) Home-work trips, walk & public transport

(c) Home-leisure trips, private transport

(d) Home-leisure trips, walk & public transport

(e) Work-leisure trips, private transport

(f) Work-leisure trips, walk & public transport
transport, but these differences are smaller than the differences observed for home-work trips. Both travel times by private and public transport are best captured by the log normal distribution.

Distance decay functions for work-based leisure trips are presented in Figure 3.3e and Figure 3.3f. The difference in travel times between home-based leisure and work-based leisure trips made by private transport are less apparent than the difference between home-based leisure and work-based leisure trips made by public transport. Again, travel times by private transport and public transport are best captured by the log normal distribution. The differences between the estimated parameters of the log normal distribution for home-based leisure trips and work-based leisure by private transport are minimal.

The estimated distance decay functions for home-based education trips are presented in Figure A.4a and Figure A.4b. As opposed to home-based work trips a large share of the trips are close to home. However, travel times for public transport are up to 60 minutes; shorter travel times for trips by private transport can be observed. No distinction between primary and secondary school trips has been made in this case, however the travel survey would allow for this distinction. If this would be done, it would be expected that many of the shorter trips are made by primary school students, whereas the longer trips would be made by students attending secondary and tertiary education.

### 3.4.2 A spatial perspective of home-based work trips in Singapore

The availability of public transport smart card data for Singapore offers the opportunity to analyse spatial interaction at a highly detailed level as it contains an almost complete sample of home work trips, as opposed to the limited number of observations given in household interview travel surveys. Instead of drawing a histogram that only depicts travel time bins, it is possible to show the spatial distribution of trips by duration and gain insight in the spatial structure. For this a series of density plots has been estimated. The R-package `spatstat` (Baddeley and Turner, 2005) has been used.

Figure 3.4 and Figure 3.5 show the density plots of start (left) and end (right) locations of home-work trips made by public transport for 15 minute
travel time intervals. Figure A.3 depicts the beelines per 15 minute travel time interval. All figures contain the MRT and LRT lines.

Figure 3.4: Start locations (left) and end locations (right) of home-work trips as observed in smart card data per 15 minute travel time bin.

Trips between 0 and 15 minutes start close to MRT stations in the western part of Singapore as well as close to the CBD located in the south. Most trips end in the CBD, indicating the speed advantage given by the MRT. Starting points of trips radiate further outward, along the MRT lines, while the end points remain firmly located in the CBD. Starting locations for trips
Figure 3.5: Start locations (left) and end locations (right) of home-work trips as observed in smart card data per 15 minute travel time bin (continued)

longer than 30 minutes the starting points are located further away from the MRT track, especially on the eastern side of the island. Also, public
housing estates in the north-eastern part of the island come into play, but only for trips longer than 60 minutes (Figure 3.4a and Figure 3.4b).

The beelines between start and end locations are analyzed in a similar fashion. Figure A.3 shows the density plots for the beelines between start and end location by 15 minutes time interval. The graphs reveal Singapore’s CBD attracts most short trips. Trips over 60 minutes mainly take place between the western and eastern part of the island.

### 3.4.3 Estimated distance decay functions: Switzerland

The estimated distance decay functions for home-work trips with municipalities with less than 50,000 municipalities are presented in Figure 3.6a and Figure 3.6b; for municipalities with more than 50,000 inhabitants the estimated distance decay functions are shown in Figure 3.7a and Figure 3.7b.

Table A.2 and Table A.3 report the estimated distance decay functions. As could be concluded from the descriptive analysis, private transport home-works trips in smaller municipalities tend to be shorter than in larger municipalities, whereas public transport trips take longer in smaller municipalities. The gamma distribution captures home-work trips by public transport best for smaller and larger municipalities. The estimated parameters how that both distributions however take a different shape. Private transport travel times in smaller municipalities is best captured by a gamma distribution; in larger municipalities it is best captured by the logistic distribution.

The estimated distance decay functions for home-based leisure trips are shown in Figure 3.6c, 3.6d, 3.7c and 3.7d. Most home-based leisure trips by private transport in smaller municipalities are shorter than 10 minutes; in larger municipalities most trips are between 10 and 15 minutes. Home-based leisure trips in smaller municipalities conducted by foot and public transport tend to be shorter than home-based leisure trips in larger municipalities. In both cases, peaks can be observed around 30 minutes and 60 minutes. Public transport trips are best captured by the gamma distribution; private transport are best captured by a log normal distribution.

Figure 3.6e, 3.6f, 3.7e and 3.7f contain the estimated distance decay functions for work-based shopping trips. As with home-based leisure trips, it can be observed that work-based shopping trips starting in smaller municipalities conducted by private transport are shorter than 10 minutes.
Figure 3.6: Estimated distance decay functions for Switzerland, trips starting in municipalities with less than 50,000 inhabitants

(a) Home-work trips, private transport

(b) Home-work trips, walk & public transport

(c) Home-leisure trips, private transport

(d) Home-leisure trips, walk & public transport

(e) Work-shopping trips, private transport

(f) Work-shopping trips, walk & public transport
3.4. *Estimated distance decay functions*

Figure 3.7: Estimated distance decay functions for Switzerland, trips starting in municipalities with more than 50,000 inhabitants

(a) Home-work trips, private transport

(b) Home-work trips, walk & public transport

(c) Home-leisure trips, private transport

(d) Home-leisure trips, walk & public transport

(e) Work-shopping trips, private transport

(f) Work-shopping trips, walk & public transport
Work-based shopping trips in larger municipalities are between 15 and 20 minutes. For trips conducted by foot and public transport, trips starting in smaller municipalities are again shorter than trips starting in larger municipalities.

The estimated distance decay functions for home-based education trips are presented in Figure A.4c, A.4d, A.4e and A.4f. Trip distributions conducted by foot & public transport reveal to have similar travel time distributions; trips starting in larger municipalities by private transport reveal to have longer travel times than trips starting in smaller municipalities.

### 3.5 Application

This section focuses on the application of the estimated distance decay functions. The distance decay functions estimated in the previous section are probability density functions, and they highlight the probability that an individual will experience a travel cost for a certain trip purpose and mode.

#### 3.5.1 Methodology

While it is possible to directly apply the estimated probability function by calculating the density of the estimate function $f(c)$ at travel cost $ij$, this will yield figures of a smaller order of magnitude than the original destination weights, as the probability of a certain travel time observation are small. Instead, as highlighted in Equation 3.3 it is chosen to normalize the probability densities by dividing the density at travel cost $ij$ by the mode of the distribution $Mo(f(c))$, under the assumption that this is unimodal distribution, and multiplying this with destination weight $d_j$.

\[
A_i = \sum_{j=1}^{n} \frac{f(c_{ij})}{Mo(f(c))} d_j
\]  

Following this approach has two advantages. First, accessibility figures will be comparable to figures found in reality; if a region has 40,000 jobs, the resulting accessibility to jobs will be in a similar order of magnitude. Second, in the spirit of Song (1996), it becomes possible to calculate the relative accessibility at origin $RA_i$ by dividing the accessibility of origin
i, $A_i$, by the sum of all destination weights $d_j$, making accessibility by different modes and different decay functions directly comparable.

$$RA_i = \frac{A_i}{\sum_{j=1}^{n} d_j} \quad (3.4)$$

A second line of thought revolves around boundary effects when measuring accessibility. Origins that are located in areas with less travel possibilities will have a lower accessibility than origins located centrally with many travel opportunities. Specifically for Switzerland and Singapore this includes origins located near national boundaries and water bodies, such as lakes and seas. While keeping in mind that higher accessibility is more desirable, it still might be necessary to correct for such boundary issues. A parallel can be drawn with the frontier bias that occurs in spatial analysis, and which can be corrected with circumferential correction (Charpentier and Gallic, 2013). It is proposed that the frontier bias that occurs in accessibility measures can be corrected by calculating the weighted average, where the weights in this case are sum of the travel costs to reach all destinations. This is also shown in Equation 3.5:

$$A_i = \frac{\sum_{j=1}^{n} f(c_{ij})d_j}{\sum_{j=1}^{n} f(c_{ij})} \quad (3.5)$$

### 3.5.2 Results

**Data sources**

The aforementioned concepts and estimated decay functions are applied to Switzerland. Intra-zonal travel times are taken from the national transport model, a four-step model. The zones have been enriched with a range of attributes, such as the number of jobs and the population. In line with the results presented in the previous section, different decay functions have been applied.

For municipalities with less than 50,000 inhabitants, the public and private
transport distance decay functions both follow a gamma distribution (with different parameters). For municipalities with more than 50,000 inhabitants, the public distance decay function follows a logistic distribution and private transport distance decay functions follow a gamma distribution. For the whole of Switzerland, accessibility to jobs by public transport follows a gamma shaped function, whereas accessibility by private transport follows a log normal function.

Results

Figure 3.8a and Figure 3.8b visualize the differences in accessibility to jobs by respectively public transport and private transport when this place-based distance decay function is applied instead of constant distance decay function over the entire country. For accessibility to jobs by public transport municipalities with more than 50,000 inhabitants have a higher accessibility to jobs than in the case where a general accessibility function is applied. These municipalities include Zurich in the north of Switzerland, Basel in the north-west of Switzerland, and Lausanne and Geneva at the south western corner of Switzerland. This is the result of individuals residing in these areas were observed to travel longer to reach their destinations. On other hand, individuals residing in municipalities with less than 50,000 inhabitants experience a lower accessibility to jobs, due to the fact that these individuals are not willing to travel as long to their workplace, as was revealed by the estimated distance decay function.

The differences in accessibility by private transport are shown in Figure 3.8c and Figure 3.8d. An opposite picture can be observed for accessibility to jobs private transport than for accessibility to jobs by public transport. Individuals residing in areas with less than 50,000 inhabitants have a higher accessibility to jobs by private transport than individuals residing in areas with less than 50,000 inhabitants. Again, this is the result of individuals residing in these areas were observed to travel longer to reach their destinations.
Figure 3.8: Differences in accessibility when applying tailored distance decay functions (a) for public transport (b) and private transport, as compared to a single distance decay function.
3.6 Conclusion

This chapter has discussed a range of concepts surrounding the measurement of accessibility. Starting with the premise that everything in a city should be accessible to everyone, different perspectives exist on the measurement of accessibility (normative versus positive, people-based versus place-based), but also in the observed travel times and travel distances to jobs and amenities.

Distance decay in Singapore follows a typical urban pattern, with few short trips, and more long trips, eventually limited by the fact that Singapore is an island. People travelling by private transport reach their destination faster than individuals travelling by public transport. Evaluating accessibility on the premise of observed trips and the commonly used exponential function might not fully capture the spatial structure of Singapore. On the premise of individuals’ preferences, it is questionable whether people prefer a 60-minute over a 30-minute commute: given the lack of distance decay, the casual observer might draw such a conclusion. Evaluating policy however, might be more desirable by means travel time thresholds or a rectangular distance decay function. Not only is such a function more easy to interpret, but clear policy goals can be set.

The analysis of the spatial structure of Singapore by means of density plots of start and end locations of public transport shows clear overlap with Singapore’s 1971 concept plan (Figure 2.1). Jobs are mainly located in the central business district on the southern tip of Singapore; the CBD is accessible by metro from high density new towns located around the central reservoir. Travel time distributions and estimated distance decay functions show the necessity to travel to this CBD for employment opportunities.

For Switzerland, an additional breakdown by agglomeration size was made in the analysis of travel times and distances, in addition to the differentiation by trip purpose and transport mode. This breakdown reveals different travel time and travel time distributions for different agglomeration sizes. These differences are most apparent for home-based work trips. Overall, individuals reside closer to their workplace than was observed in Singapore.

For both countries, the differentiation by trip purpose reveal a clearly different pattern. Most notably, work-based shop and leisure activities take place in a limited space around the work location, this effect being more
clearly observable for work-shop trips performed by public transport.

The differentiation by travel mode also reveals different travel time patterns between both countries. In Singapore and larger municipalities in Switzerland individuals tend to travel longer to work by public transport, where observed travel times in Singapore tend to be longer. It should be noted though, that Singapore, as city-state, is many times denser than the larger metropolitan areas in Switzerland, which can result in higher travel times in Singapore. Home-leisure trips, on other hand, tend to take place closer to the residence than in Switzerland, where leisure trips up to 60 minutes travelling from the residence can be observed.

Distance decay functions by trip purpose and travel mode were estimated, with different functional forms. Dependent on the purpose and mode different functional forms proved to have the best fit with the underlying travel time observations.

These tailored distance decay functions have been applied for Switzerland. Most notably, a higher accessibility to jobs can be observed in urban areas by public transport, and a lower accessibility in rural areas.

For both countries, reported travel times have been used for the descriptive analysis as well as for the estimation of the distance decay functions. GPS-based surveys using smart phones or other types of activity trackers can provide more accurate insight in experienced travel times. For the application of the estimated distance decay function use has been made of intra-zonal travel times originating from a four-step demand model. A higher level of resolution is possible, either by using results from a highly spatially disaggregated transport demand model, or by using travel times from route planners that make use of a loaded network or other means to express uncertainty in travel times (e.g. Wigginton Conway et al., 2017).

The next chapter will look closer at the measurement of pedestrian and transit accessibility on a micro-level, and makes use of highly disaggregate travel times as well as realistic distances to reach transit. Chapter 5 investigates the measurement of diversity and accessibility to amenities.
Chapter 4

Pedestrian and transit accessibility on a micro-level: results & challenges

This chapter was published in van Eggermond and Erath (2015)

4.1 Introduction

Transportation researchers generally refer to accessibility as a measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome this spatial separation or 'the potential of opportunities of interaction' (Hansen, 1959).

While the concept of accessibility has been known since the 1950’s, it has only recently drawn attention from practitioners as one attractive indicator measuring the combined effects of transport policies and urban planning. If accessibility measures are considered in transportation planning, mainly zonal, car-based accessibility measures are considered (Handy and Clifton, 2001a).

The usage of the term accessibility in everyday life is clearly less abstract than the notion of accessibility as used in transportation research. Here accessibility can refer to aspects surrounding mobility ranging from buildings being accessible by a ramp, to low-floor buses, improving access to the bus from the bus stop and distance to transit. While this practical
definition gives insight in aspects of importance when measuring the door-to-door travel experience, it lacks the concept of reaching destinations and the travel time required to reach these destinations.

Walking, cycling and public transport are seen as modes that can reduce the negative externalities caused by the use of the automobile, such as congestion, particle emissions and noise emissions. Moreover, these modes are equitable, given by equal access to every healthy person and active modes such as walking and cycling provide additional health and recreational benefits. The popularity of these modes is, amongst others, dependent on the level of accessibility provided as compared to the automobile. However, a clear disparity exists between private and public transport accessibility (e.g. Levinson, 1998; Shen, 1998; Hess, 2005; Kawabata, 2009; Benenson et al., 2011; Salonen and Toivonen, 2013).

To make walking and transit an attractive and viable mode of transport it is necessary to account for the door-to-door travel experience; everyday usage of accessibility clearly reflects this necessity. In the case of public transport, this can be done by increasing headways, improving reliability and improving the access to transit. Improving pedestrian accessibility and the attractiveness of walking can be realized in numerous ways, such as ensuring that walks are useful (e.g. mixed use), safe, comfortable and interesting (Speck, 2012), but also by minimizing the difference between beeline and network distances (Weinstein Agrawal et al., 2008).

Accessibility can be computed in several ways. Not only do different types of accessibility measures exist (e.g. Bhat et al., 2002), the operationalization of these measures also differs in terms of the level of granularity, the travel time used and the weighting function. Iacono et al. (2010) argue that difficulties in calculating accessibility for non-motorized transport measures arise from problems with data, the zonal structure of transportation models and transport networks for describing travel by non-motorized modes. Due to their nature, travel times of walking, cycling, but also of public transport trips are hard to derive from traditional zonal models. Public transport operates within a small catchment area surrounding the transit stop; walking and cycling are mainly used for shorter trips which are not well represented in zonal models.

It is possible to measure the walking time to opportunities, including transit stops, in a range of ways. Euclidean and Manhattan distances are often used for their simplicity. More realistic pedestrian distances are
calculated by means of network distances over road center lines.

This study contributes to previous work by explicitly comparing the outcomes of accessibility computations when different types of pedestrian networks are used to calculate walking times, but also to calculate door-to-door travel times for public transport. By following this approach and by approximating walking distances with pedestrian networks, the local urban environment is connected to the larger transport system, thus making it possible to evaluate local measures aimed to improve accessibility, and to support local planners and citizens with tools to assess and improve accessibility.

Also, by explicitly outlining the different steps followed to calculate accessibility, we aim to highlight different elements of relevance when calculating high resolution accessibility indicators and provide input to discussions surrounding accessibility computation.

Prior to presenting results in section 4.4, section 4.2 will present a brief overview of accessibility measures. Section 4.3 will discuss the methodology followed in this paper and the available data. Section 4.5 concludes with remaining challenges for the measurement of combined pedestrian and transit accessibility.

4.2 Measuring accessibility

Geurs and van Wee (2004) identify four components that are relevant when measuring accessibility: (1) a land-use component, (2) a transportation component, (3) a temporal component, and (4) an individual component. An ideal accessibility measures would take these four components into account. These four components all have in common that they relate to the destination and the ease of reaching those destinations. Five main types of accessibility measures have emerged in literature, all containing one or more of these four components.

Five main types of accessibility measures have emerged in literature, all containing one or more of these four components. Bhat et al. (2002) provide an overview of these five types:

1. Spatial separation: The only dimension used in this measure is the distance; it does not consider attractions. However, the most general of these measure consists of the weighted average of the travel times
to all other zones under consideration.

2. *Cumulative opportunities*: This measure takes into account both the distance and the objective of a trip; a travel time or distance threshold is defined and uses the number of potential activities within that threshold as the accessibility for that spatial unit.

3. *Gravity measures*: This measure includes an attraction factor as well as a separation factor. While the cumulative-opportunities measure uses a discrete measure of time or distance and then counts up attractions, gravity-based measures use a continuous measure that is then used to discount opportunities with increasing time or distance from the origin.

4. *Utility measures*. Two groups of utility measures exist:
   - *Generalized cost measures* estimate total travel costs to go from an origin to a destination, including all relevant time aspects, out-of-pocket costs and the comfort quality aspect.
   - *Logsum measures* are based on random utility theory and interpret accessibility as the outcome of a set of transport choices. This is calculated by taking, for an individual \( n \), the expected value of the maximum of the utilities \( (U_{in}) \) over all alternative spatial destinations \( i \) in choice set \( C \). The utility is determined by taking the logsum of \( V_{in} \). This is a linear function with elements representing factors related to accessibility such as the quality of the attraction and the travel costs associated with reaching that attraction.

5. *Time / space measures* are founded in the space-time geography of Hägerstrand (1970). He used a three-dimensional prism of the space and time available to an individual for partaking in activities. The motivation behind this approach to accessibility is that individuals have only limited time periods during which to undertake activities. As travel times increase, the size of their prisms shrink.

The first three types of accessibility measures are closely related; they consider a transport component (distance) and a number of opportunities that can be reached. It is possible to further specify these measures to approximate preferences of groups or individuals. For instance, modes and / or opportunity types can be excluded from calculations or opportunities can be further categorized. In addition to a description of the opportunities and distances, gravity measures require an impedance parameter. This
parameter is usually estimated on survey data and is mode and trip purpose dependent; they are however generally considered constant across different user groups.

### 4.2.1 Pedestrian accessibility

Despite a wide range of studies calculating or applying automobile accessibility, much less attention has been paid to the calculation of pedestrian accessibility. Handy and Clifton (2001b) identify a gap between data the needed to describe local accessibility, such as data describing the transport network and the location of opportunities, and data available to planning departments. They propose a dual strategy to overcome this gap: a city-wide strategy using available data and the capabilities of GIS and a neighborhood-specific strategy that asks residents themselves to build a detailed accessibility database as a part of a neighborhood planning process. Iacono et al. (2010) highlight the same issues: problems with data, the zonal structure of transportation models and transport networks for describing travel by non-motorized modes. One recent example to calculate pedestrian accessibility is WalkScore (WalkScore, 2014). WalkScore gives full points to amenities within a 5 minutes walk (or 400 meters) and employs a decay function to more distant amenities located; beyond a 30 minute walk no more points are given. Two versions of WalkScore exist: a version only considering crow-fly distances between origins and destinations, and more recently, a version considering network distances. Previous data limitations are overcome by using points of interest databases and online network data. Network distances however are road centre line distances; crossings and building entrances are not included in the calculation.

Research has recognized the need for more detailed pedestrian networks. Karimi and Kasemsuppakorn (2012) present an extensive review of pedestrian network map generation approaches. A distinction can be made between three main approaches: network buffering, collaborative mapping with GPS traces and image processing. Of these approaches, network buffering requires the least computation effort; image processing most. The goal of the reviewed studies is mainly to generate pedestrian maps and not so much to generate routable pedestrian networks suitable for accessibility analysis.
4.2.2 Public transport accessibility

Public transport differs from other modes of personalized transport in the sense that it is bound to transit stops, routes and schedules. In practice and research different methods for calculating accessibility can be found. The Public Transport Accessibility Levels (PTALS) methodology was developed for the London Borough of Hammersmith and is implemented across London. PTAL measures the accessibility of a point to the transport network. The methodology only considers the access to transit; connections of transit to the remainder of the transit system and subsequently to opportunities is not included in the calculation method. A more or less similar approach is followed in Switzerland by the federal spatial planning department (ARE, 2014), which use Euclidean distances to transit instead of network distances and make a distinction between different types of transit.

Transit accessibility research has focused on the calculation of more realistic transit travel times, by incorporating spatially and temporally different travel speeds, waiting times and transfer times and transfer waiting times (see Salonen and Toivonen, 2013). The availability of transit data, network data and computational resources has opened up opportunities to calculate accessibility on a door-to-door level (Benenson et al., 2011; Lei and Church, 2010) and to offer public transport travel accessibility calculation as a web service (OpenTripPlanner, Byrd, 2012). OpenTripPlanner uses an open data format for public transport schedules and the openly available OpenStreetMap. OpenTripPlanner calculates the accessibility for a single point in time and single location. Results thus differ based on the chosen starting point, and more importantly, the chosen start time. Results are then dependent on the headway of the transit service. OpenTripPlanner has been applied for the Minneapolis/St. Paul region (Owen and Levinson, 2015). By calculating the cumulative opportunity transit accessibility to jobs for different travel time bands, and for every minute in the morning peak an average and maximum accessibility is calculated. The underlying pedestrian network is based on OpenStreetMap; the connection between destinations and the road network is not readily defined.
4.3 Methodology, Study Region & Data

4.3.1 Methodology

In this study we calculate accessibility with door-to-door travel times and thus account for every stage in a journey. If the four components of accessibility identified by Geurs and van Wee (2004) are translated to the building level, this leads to the following challenges: (1) **Land-use**: The measurement of opportunities on a building-fine level, (2) **Transport**: The incorporation of non-motorized modes and transit and the connection of the transport network to opportunities, (3) **Temporal**: Measuring transportation system performance and the availability of opportunities by time of day and (4) **Individual**: Taking into account the abilities of individuals to participate in the (non-motorized) transport system and the attractiveness of different opportunities to different individuals.

4.3.2 Study region

As a case-study for this study we consider the city state of Singapore. Singapore is located in Southeast Asia with a land area of 712 km$^2$, a permanent residential population of 3.77 million and a total population of 5.08 million in 2010, compared to respectively 697 km$^2$, 3.27 million and 4.03 million in 2000. GDP per capita amounts to S$ 59,813 (US$ 45,200, 2010), which makes it one of the wealthiest countries in (Southeast) Asia. Together with the increasing population and wealth, vehicle ownership has increased from 392,961 in 2000 to 597,746 in 2010, or from 1 car per 10 households in 2004 to 1 car per 8.8 households in 2008 (Choi and Toh, 2010). The total number of motorized vehicles is close to 1 million. While the car has long been the mode of choice, the combination of an increasing population and a limited amount of certificates of entitlement to vehicles being available for auction, vehicle ownership has become a financially unattractive option to many households. Both the Singapore Land Transport Authority and the Urban Redevelopment Authority are seeking ways to make public transport more attractive on one hand and bringing jobs closer to residences on other hand.
4.3.3 Available data

Opportunities: Jobs

Building fine opportunities are available for several activity types. In this study we consider the the number of jobs per building. Chakirov and Erath (2012) have identified workplaces in Singapore by analyzing public transport smart card data; these workplace have been inflated by mode share per TAZ as observed in the Household Interview Travel Survey 2008. Subsequently, Ordóñez Medina and Erath (2013) distributed public transport trips identified to be commuting journeys to individual buildings by means of an iterative proportional fitting. The entire calculation environment according to object-oriented design principles. In this paper we present accessibility to jobs. However, in each building object additional attributes are stored such as the number of residential units, land-use type, and several points of interest.

Non-motorized transport: the case of the pedestrian

In this study we compare two pedestrian networks with a base scenario in which Euclidean distances are considered. Before proceeding to the differences between the two pedestrian networks, the commonalities will be highlighted. As a basis for both networks the 2008 road centre lines of the Singapore Land Authority (SLA) are used. This network has been chosen as the network coverage is comprehensive and the links are categorized by road category. Expressways are considered not be available to pedestrians and are excluded from both networks.

Building footprints and accompanying addresses are available for 2008 from the Singapore Land Authority. These footprints are matched to road centre lines by means of the shortest line between building centroid and roads with a name corresponding to the address of the building; each address can only have one line connected to the network.

Figure 4.1 gives an overview of the data sources used for the generation of both pedestrian networks.

Two pedestrians networks are generated. The first network consists of walkways on road centre lines; a fairly traditional approach. It is assumed, that each link is a sidewalk and dedicated crossings are not necessary. A building located on one side of a road can be directly accessed by a building located on the opposite side of the same road. Pedestrian overhead bridges and underpasses are however added to this network if they intersect two or more road centre lines. Bus stops, obtained from the Land Transport
Authority (LTA) are matched to the road by means of shortest line. Mass Rapid Transit (MRT) stations are obtained from LTA as well. Entrances and exits to these stations were downloaded from an online directory (Streetdirectory, 2013) and matched to MRT stations by name. These entrance and exits are connected to the road centre lines by means of shortest lines. MRT entrances and exits are connected to the MRT station.

In addition to the road centre lines, a number of additional data sources are used in the generation of the second pedestrian network, the 'offset' pedestrian network. This network generation approach is inspired by the work of Parker and Vanderslice (2011) and Kim et al. (2009). Both studies propose methods for pedestrian network generation using centre lines as a basis; however, their focus is not so much on creating a routable pedestrian network but to highlight possible sidewalk generation approaches.

In the road network a distinction is made between nine road categories. Five road categories are assumed to have sidewalks on both side of the road; a common feature in Singapore. For one category the centre line is used. The decision whether a certain road category has a sidewalk on both sides of the road or whether the road centre line is a walkway was made by sampling roads and inspecting them with Google Streetview. Pedestrian crossings are sourced from several data sets. Pedestrian overhead bridges, pedestrian underpasses are added to the offset road network. Pedestrian traffic lights are available but are not coded in pairs, making the matching of the traffic lights to the pedestrian network difficult; therefore these are currently not included in the network. Lane markings indicating a pedestrian crossing are added where lane markings intersect road centre lines. Lane-markings not crossing a road centre line are evaluated based on their distance to road centre lines and the angle between the road centre line and the lane marking. Pedestrians are always required to use a crossing. It should be noted that certain road categories are hard to cross mid-block due to the large number of lanes, and fences placed along sidewalks (one-way roads) or in the middle of the road (two-way roads). One road category has the possibility to be crossed in some cases mid-block; this is not considered in the current network.

By following this approach we create a network that provides a fixed and formal description of the network. In literature other methods can be found for the modeling of pedestrian movement, such as agent-based methods. They offer more flexibility in the types of input data used (e.g. Penn and
Such methods would for instance allow for mid-block crossing and the crossing of squares. However, a pedestrian network offers better computational performance. More importantly, the question is whether one wants to account for mid-block crossings and jaywalking for planning purposes.

The Singapore climate and walking environment contains elements which could be considered discouraging for walking, such as a high humidity, overhead bridges and underpasses. While the offset pedestrian network distances can approximate distances along roads, perceived costs at grade crossings, overhead bridges and underpasses are underestimated as the number of lanes being crossed is not yet taken into account just as waiting times at signalized intersections, which can amount to 150 seconds, and in the case of large roads twice this amount, as it is necessary to wait a second time halfway during the crossing. Furthermore, generalized costs for these types of crossings are not yet considered, as are generalized costs regarding the sidewalks. These costs are discarded as no information is known of the relative weighing of attributes. Finally, the limitation of only one link between each building and the network is known not to represent reality in all case. Social housing, shopping malls and parks are mostly connected to more than one link in the network as effort has been made to make these environments pedestrian friendly. However, taking these limitations into account, the generated pedestrian networks offer the opportunity of connecting the public transport system to individual activity opportunities, thus connecting the macro transport system to the micro-level.

Public transport travel times
Public transport travel times are calculated with an implementation of a multi-agent, activity-based (MATSim), transport demand model of Singapore (Erath et al., 2012). The implementation of MATSim used in this study simulates smart card data, in which over 4,500 bus stops, 80 Mass Rapid Transit (MRT) stops, and over 30 Light Rapid Transit (LRT) are included. 25% of the daily 4.5 million public transport trips are simulated. As a simulation of only the public transport system would lead

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1These costs have been quantified based on stated preference and revealed preference data in a subsequent project conducted at the Future Cities Laboratory / Singapore ETH Centre. While the costs for crossings equal approximately half the cycle time, the perceived travel time for crossing an overhead bridge is perceived higher; travel times for walkways with cover or adjacent to shop front reduce perceived travel time. See Erath et al. (2016)
Methodology, Study Region & Data

Figure 4.1: Pedestrian network generation. Source data (left) and offset pedestrian network (right)

...to unrealistically low travel times as no interaction with other modes takes place, link travel times and bus stop dwell times are estimated by using time stamps recorded in smart card data. The result of the iterative simulation is a temporally dynamic network with the average travel time for each link per 15 minute interval over the 24-hour time span. Subsequently, all possible transit stops combinations are routed on this loaded network. The shortest path algorithm returns the shortest transit time for each 15-minute interval, including transfer time and transfer walking time if applicable. The routing algorithm considers different taste parameters for in-vehicle time, transfer waiting time and transfer walking time. These parameters are calibrated for the Singapore MATSim model.

Execution of the accessibility calculation
The calculation of building-fine accessibility indicators is split into a number of steps for both computation and validation purposes. All computations have been carried out in a multi-threaded environment on a HPC using a combination of JAVA, the Java Topology Suite (JTS), Postgres and PostGIS. The results of each step are stored for further analysis. This section will discuss the steps carried out and the respective parameter settings in each step.
Transit travel times
In this study we consider the period between 7am and 9:30am of an average weekday, corresponding to the morning peak hour. For each 15-minute interval in this period the transit time from each transit stop to each other transit stop is available; the median of these travel times is used in further accessibility calculations.

Selection of candidate transit stops
Euclidean distance and network distances between buildings and transit stops within a radius of 1000 meters of each building centroid are calculated. Out of the 113,406 buildings considered, 112,040 buildings have a transit stop within a 1000m radius, 108,164 buildings have a transit stop within 1000 meters network distance considering a simple pedestrian network and 106,850 buildings have a transit stop within a 1000 meters offset network distance. Figure 4.2 shows the number of buildings that have a transit stop within a certain distance; colours indicate the type of transit. Over 86% of the buildings have a transit stop within 300 meters if Euclidean distances are considered. If simple network distance are considered, this value drops to 52%. If the offset network is considered, 47% of the buildings have a transit stop within 300 meter distance.

On average each building is connected to 39 transit stops within 1000 meters euclidean distance. The average number of transit stops drops to 16 (1000 meter network distance) and 13 (1000 meter offset network distance).
Calculate pedestrian accessibility
Pedestrian accessibility is calculated by calculating the Euclidean distance and network distances between each building and all other buildings within a 1000 meter radius or 1000 meter network distance respectively. Calculated distances are converted to a travel time assuming a walking speed of 4 km/h. Currently, the accessibility computation and accompanying distance decay function are implemented:

$$A_i = \sum_{j=1}^{n} d_j \exp(\alpha t_{ij})$$

(4.1)

where $A_i$ is the total accessibility of building $i$, $d_j$ are the opportunities at destination $j$, $\alpha$ is the distance decay (impedance) parameter and is the total travel time between $i$ and $j$. Job and residential opportunities are discounted assuming an impedance factor of -0.2 for job opportunities as well as for residential opportunities. This impedance factor is based on survey data (Erath et al., 2012). Opportunities reached walking are subsequently excluded from the total set of opportunities.

Calculation of transit accessibility
The travel time between each origin building, candidate transit stops for this building and the transit travel time between each transit stop is calculated in the previous steps. In the final step the options between each destination building and its’ candidate stops are evaluated. Again function 4.1 is used to calculate the accessibility of a building. The route with the shortest travel time, consisting of the walking stage from the origin, transit time and the walking stage at the destination end of the trip, is selected for the accessibility calculation. Again, a walking speed of 4 km/h is assumed. Furthermore, only transit stops within 700 meter (Euclidean & network) distance are selected as candidate transit stops. This parameter is currently used for analysis purposes of the algorithm; in the future this parameter will be replaced by a maximum distance for a bus stop and a maximum distance for a MRT stop. These parameters will be based on the Household Interview Travel Survey.

Calculation of total accessibility
In the previous steps walking distances have been converted to travel times in minutes. Transit times have also been converted to minutes. Total
job accessibility for a single building is calculated as the sum of transit accessibility and pedestrian accessibility.

4.4 Results

This section presents the results of the accessibility calculation. All transit accessibility measures include all possible buildings as destination in Singapore. Computing pedestrian accessibility for buildings within a 1000 meter radius is a matter of seconds; calculating transit accessibility is highly dependent on the number of alternative routes to be evaluated and takes longer. Overall, the algorithm is robust but heavily dependent on the quality of the input data. This will be highlighted later in this section.

In this paper we present the results of a number of selected zones. These
zones are depicted in Figure 4.3 and consist of the main shopping belt Orchard Road starting in the West and sloping down to the East, the Downtown Core and Museum District at the east end of Orchard Road. Orchard is considered to be the prime shopping district in Singapore. Its main road, Orchard Road, is a five-lane, one-way road. Crossing is only possible at a limited number of underpasses and grade crossings. Newton is a residential district situated on the north side of Orchard Road, River Valley is the residential area south of Orchard Road. Singapore River, Outram and Rochor contain heritage quarters and have a fine-grained street pattern. Table 4.1 presents key indicators of the selected zones; the Downtown Core and Orchard have the majority of jobs while the other zones are mainly residential.

Table 4.2: Selected planning zones and average pedestrian and transit accessibility per building

<table>
<thead>
<tr>
<th>Planning zone</th>
<th>Pedestrian accessibility to jobs (Euclidean)</th>
<th>Pedestrian accessibility to jobs (Centre-line)</th>
<th>Pedestrian accessibility to jobs (Offset)</th>
<th>Transit accessibility to jobs (Euclidean)</th>
<th>Transit accessibility to jobs (Centre-line)</th>
<th>Transit accessibility to jobs (Offset)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtown Core</td>
<td>27,182</td>
<td>11,583</td>
<td>8,152</td>
<td>43,564</td>
<td>21,936</td>
<td>20,210</td>
</tr>
<tr>
<td>Museum</td>
<td>13,764</td>
<td>4,104</td>
<td>3,536</td>
<td>51,319</td>
<td>24,075</td>
<td>21,455</td>
</tr>
<tr>
<td>Newton</td>
<td>11,242</td>
<td>2,791</td>
<td>1,922</td>
<td>33,290</td>
<td>10,048</td>
<td>8,671</td>
</tr>
<tr>
<td>Orchard</td>
<td>15,566</td>
<td>6,484</td>
<td>4,741</td>
<td>51,120</td>
<td>24,137</td>
<td>21,503</td>
</tr>
<tr>
<td>Outram</td>
<td>23,047</td>
<td>8,266</td>
<td>5,466</td>
<td>31,803</td>
<td>15,356</td>
<td>13,620</td>
</tr>
<tr>
<td>River Valley</td>
<td>8,844</td>
<td>1,847</td>
<td>1,361</td>
<td>27,503</td>
<td>12,726</td>
<td>11,048</td>
</tr>
<tr>
<td>Rochor</td>
<td>10,222</td>
<td>4,148</td>
<td>3,488</td>
<td>34,424</td>
<td>17,042</td>
<td>14,440</td>
</tr>
<tr>
<td>Singapore River</td>
<td>25,170</td>
<td>10,890</td>
<td>3,954</td>
<td>40,254</td>
<td>18,314</td>
<td>11,174</td>
</tr>
</tbody>
</table>
Results on a zonal level
In Table 4.2, the average accessibility per building per planning zone is shown. For both pedestrian and transit accessibility a drop can be observed between computations using Euclidean distances between opportunities and network distances. In the Downtown Core, Rochor and Singapore River the smallest decrease can be observed. This reflects the dense street pattern in these zones. Differences in accessibility between the centre-line and offset network for pedestrian accessibility can also be observed, albeit smaller than as compared to Euclidean distances. The Downtown Area is well connected by underpasses and grade crossings; the zones Singapore River and Rochor contain streets that can be crossed at any point. A second reason for the small difference between the results of both pedestrian networks can be that the length of grade crossings, overhead bridges and underpasses is limited in this study to 5 meters. The drop between Euclidean and network-based pedestrian accessibility is much steeper in the planning zones Museum, Newton and River Valley. The latter two planning zones have a large number of condominiums and a low number of crossings, leading to a low pedestrian accessibility. The drop in transit accessibility is also visible, but is less steep. This indicates that a low number of job opportunities is available in these zones and motorized transport is required to reach job opportunities.

Results on a building level
Figure 4.4, 4.5 and 4.6 place the results in a spatial context. The top figure shows accessibility for the case when public transport is connected to buildings by means of Euclidean distance, the middle figures when a road centre-line network is used for walking distances and the bottom figure shows accessibility when offset network distances are considered. Legends are explicitly chosen to be in the same range to allow for direct comparison. It can be seen that buildings near transit stops have a high job accessibility in the Downtown Core and Orchard Road. The zones Newton to the top and River Valley below have a low transit accessibility, with the accessibility values dropping quicker in the case of centre-line and offset distances, as expected. The differences between centre-line and offset based accessibility are less apparent from Figure 4.5 and Figure 4.6. Differences can be found in accessibility when comparing buildings on both sides of major roads. This is probably because of the detour required to reach transit stops in the case of the offset network.
Figure 4.7 shows the relative difference between Euclidean and network-based transit accessibility per building. Differences in accessibility are smallest for buildings near transit stops; an intuitive result. Also, differences are smaller in areas having smaller buildings and finer-grained street pattern. Examples are the 'Little India’ district of the Rochor Planning zone in the top right and the 'China Town’ district in the Outram / Singapore River planning zone in the bottom right.

This visual comparison also highlights the challenges when computing accessibility on the micro-level. Figure 4.4 shows high accessibility for the area in the far right, indicated by the letter 'M'. Accessibility when considering road centre-line distance for this area are lower, while accessibility values when considering the offset network distances drop even further. Closer inspection tells us that there is limited number of grade crossings in this area; this is reflected in the offset pedestrian network. However, in real-life the area contains large shopping malls which can be traversed, as well as an underground mall. These pathways are not yet included in the pedestrian model. Research is however required if these mall are accessible 24 hours per day to pedestrians, and if these indoor pathways are known to pedestrians. The second case concerns Raffles Places, demarcated by an 'R' in the bottom of all accessibility maps. Raffles Place is one of the main centres of the Downtown Core and is well connected by the two main MRT lines. Closer inspection in this case reveals that buildings in this area have 'Raffles Place’ as address but that Raffles Place as street is not included in the road network, as it is a car-free, pedestrian-only square. Near 'Raffles Place’ a smaller street block is not connected to the larger network. In this, closer inspection shows us that based on the road category crossings are required; the official, source data however does not contain these crossings. These cases highlight the need for highly detailed data and but also for the need of comparison with ground-truth.
Figure 4.4: Transit accessibility to jobs, euclidean distances to transit

Figure 4.5: Transit accessibility to jobs, centre-line pedestrian network
4.4. Results

Figure 4.6: Transit accessibility to jobs, offset pedestrian network

Figure 4.7: Relative differences between Euclidean and network-based transit accessibility per building
4.5 Conclusions & remaining challenges

4.5.1 Conclusions

This work has presented a combined pedestrian and transit accessibility measure and quantified this measure for the central area of Singapore. Transit stops have been connected to a pedestrian network; for train stations an additional effort has been made to include entrances and exits. It has been show that job accessibility strongly decreases if, instead of Euclidean distance to transit stops, network distances are considered. Differences in accessibility measures, considering different pedestrian distance estimates, are smaller in areas with a dense street pattern and smaller parcel sizes. The accessibility of buildings near a transit stop indicates how well jobs can be reached from this transit stop; a factor important when considering the quality of public transport on a larger scale. Other types of activity opportunities are not yet in included in the calculations. Results are dependent on the quality of the input data. A pedestrian network based on offset centre lines requires additional data sources to include pedestrian crossings. The fact that this data is not readily available, might indicate that transport and land-use authorities currently not have the tools necessary to analyze pedestrian accessibility. For certain types of buildings (shopping malls, condominiums, public housing), a closer look is necessary at the connection of buildings and parcels to the network. Accessibility calculations do not differ much between the two types of pedestrian networks. On one hand this is a comforting result, as it indicates that our offset pedestrian network is well-connected to points of interest in the network. On other hand this result might be seen as surprising; extra analysis is required to compare the generalized costs of routes instead of distances between the two networks.

4.5.2 Remaining challenges

Classifying opportunities, destination similarity and destination competition

While data is available concerning shopping malls, food centres, coffee shops, schools, supermarkets and a wide range of other opportunities it is the abundance of data and the necessary categorization of the data that concerns us. Therefore we plan to investigate the valuation of similar activity opportunities in the destination set. This similarity investigation
will include a directional component; i.e. are amenities in the same direction or at the same location valued more or less than amenities spread out through space. Furthermore, when measured on the local scale it is expected that amenity categories have to be reformulated; individual A might prefer coffee S and the price level of supermarket Y where individual B can prefer coffee T and the price level of supermarket Z and would thus value coffee shops and supermarkets differently than individual A. However, does this create the necessity to create a category for each type of coffee shop and each supermarket brand? On other hand, accessibility is about reaching destinations. It can also be argued that reaching simply reaching more destinations, and having more choice, is beneficial.

Pedestrian network generation with open source data and generalized link costs

A second challenges lies in the generation of pedestrian networks, the assignment of general costs to the links and the generation of different networks for different user groups. The network generation approach followed is heavily dependent on proprietary data sources and different sets of rules for different crossing types, but can easily be changed to open data (e.g. OpenStreetMap). Surprisingly, despite the data sources used in this study contain a tremendous amount of information of relevance to a pedestrian network, the information stored is not suitable for pedestrian network generation and the analysis non-motorized accessibility, as previously recognized in literature (Handy and Clifton, 2001a; Iacono et al., 2010). When considering accessibility on a micro-level the modeling of connection between buildings and the network becomes important; an approach solely based on a connection between buildings and roads with the same road name, especially in shopping malls and Singaporean housing estates, which have extensive pedestrian walkways, is not sufficient. However, simply connecting buildings to the $n$ nearest links might also not be representative of reality. First steps to include housing estates, parks and malls in a network combined with grid cells have been made (X). Public transport travel times are currently based on the results of an agent-based simulation. However, for a large number of cities public transport schedules are available in the form of the General Transit Feed Specification (GTFS). While GTFS only represents the transit schedule and not the real-life execution, the data is available for a wide range of cities and regions.
Parameter settings and accessibility algorithm A third challenge can be found in setting of the different parameters, such as destinations that can be reached walking and the maximum distance to transit stops. Walking distances can be extracted from household travel surveys; a maximum walking distance for destinations to be considered accessible by foot is harder to estimate as it is highly likely that non-motorized trips are under reported. Calculation time is very much dependant on the number of options to be evaluated. While the accessibility calculation for a single building is still acceptable (a matter of seconds), computations for entire districts are much longer. Decreasing the number of transit stops building combinations will decrease the number of origin end and destination end travel alternatives to be evaluated; especially in the city centre a large amount of transit stops are included in calculations. A second option is to decrease the number of destinations to be evaluated, either by setting a cut-off time or by considering only buildings with certain opportunity types. Finally, the possibilities to implement a distance decay function suitable for short distances (Martínez and Viegas, 2013) needs to be explored.

Interactive visualization and application
The current visualizations are static; all results are pre-computed and stored in a database. In line with the possibilities of OpenTripPlanner Analyst (Byrd, 2012), it is envisaged that users can interact with different parameter settings and to take the possibilities a step further by offering users the possibility to change the pedestrian network and evaluate the changes in accessibility. By following this approach, we hope that it is possible to truly connect the far to the local and support local planners and citizens with tools to asses and improve accessibility.

4.6 Acknowledgements
The research conducted at the Future Cities Laboratory is co-funded by the Singaporean National Research Fund and the ETH Zurich. The authors would like to thank Professor Kay W. Axhausen for his suggestions and comments. Also, we would like to thank Sergio Ordonez Medina with his help calculating transit travel times. We wish to express our gratitude to the Land Transport Authority for providing us invaluable data sets on transport in Singapore. We are very thankful to the Singapore Land Authority for providing us with a wide range of data sets.
Chapter 5

Local accessibility, diversity and density

This chapter is based on van Eggermond and Erath (2016)

5.1 Introduction

An attractive urban setting is easily recognised, but quantifying them is a bit harder. An easy analogy is drawn with Galster (2001) on neighbourhoods: "neighbourhoods are treated in much the same way as courts of law have treated pornography: as a term that is hard to define precisely, but everyone knows it when they see it". Characterising and quantifying the built environment remains an elusive concept with many pitfalls. Commonly, diversity is judged by land-use plans and categorised by broad descriptions, such as ‘commercial’ and ‘industrial’.

It has been shown that the built environment influences travel behaviour, health outcomes and even happiness. To describe the built environment, researchers have long employed measures describing the built environment. Cervero and Kockelman (1997) coined these measures ‘density’, ‘diversity’ and ‘design’ - the three ‘D’s’. Measures that fall in these categories include: population density, intersection density, jobs-housing balance, distance to the nearest transit stop, and travel time to work. From various meta-analyses (e.g. Ewing and Cervero, 2010) one can conclude that the built environment influences walking. However, inferring general conclusions from different studies remains a challenge. Zegras (2010) points out to several of these challenges: scales of analysis differ, built environment measures vary, the travel behaviour data used varies, control variables employed differ and the
ultimate outcomes measured are different. Making comparison between study areas difficult, if not impossible.

In this chapter several ways to measure the diversity are presented, compared to existing diversity measures and its relevance for both urban science and city master planning are assessed. Subsequently, a diversity and destination index based on point of interest data is proposed. The chapter concludes with a series of models describing the choice to walk in Singapore and Switzerland. Use is made of the Swiss and Singaporean household interview travel survey, publicly available road network data and point of interests available from an online data source.

5.2 Measuring diversity: an ecological perspective

Ecologists have traditionally employed a range of diversity indexes to describe the contribution of biodiversity to the functioning of ecosystems; many of the indices used in transport and land-use planning stem from ecology.

In order to describe the species diversity of an ecosystem, different structural characteristics of the system under study can be considered: (1) the number of different species in the system, (2) the characteristics features of the different species and (3) the relative abundances with which the species are distributed over different species (Baumgärtner, 2006).

Two strands of indices can be recognized. The first strand weighs the species according to their relative abundance in the system and are called distributional indices. The second strand stresses that the different species should be given a different weight according to their different characteristics and can be seen as dissimilarity indices or measures of variation (Baumgärtner, 2006; Ritsema van Eck and Koomen, 2008). Studies measuring land-use diversity borrow from the distributional indices; these will be discussed below.

The most basic diversity index is the species richness $m$. This index simply counts the number of species found in the system and ranges from 0 to $m$. In this index, all species are counted equally, and all other information on the species is ignored.
A second diversity index, the Berger-Parker index, measures the abundance of the most common species in the system as:

\[
D_{BP} = \frac{1}{p_{\text{max}}}
\]  

(5.1)

Where \( p_{\text{max}} \) is the abundance of the most common species in the system; information on all other species is ignored in the calculation of the Berger-Parker index.

A third diversity index stems from statistics and information theory and is known as the Shannon-Wiener index:

\[
D_{SW} = -\sum_{i=1}^{m} p_i \ln p_i
\]  

(5.2)

The index varies from 0 if no diversity is present to \( \ln m \) if all species are equally present. The Shannon-Wiener index allows for the hierarchical decomposition of species into different levels of disaggregation; the upper level entropy can be additively decomposed in lower subsystems (e.g. males / females, or different types of commercial land-uses).

The species evenness is given by dividing the Shannon-Wiener index by the number of species

\[
E_{SW} = \frac{D_{SW}}{\ln m}
\]  

(5.3)

The evenness varies between 0, if only 1 species is present, and 1, if all species are equally present.

The Simpson index is another popular measure in ecology to measure biodiversity. This index gives the probability that any two species drawn from the same population belong to the same class and is formulated as:

\[
D_S = \frac{\sum_{i=1}^{n} n(n-1)}{N(N-1)}
\]  

(5.4)

The Simpson index yields a low value for a population with a high
diversity. As this counter-intuitive for a diversity index, transformations are often applied. The Gini-Simpson index is calculated as:

\[ I_S = 1 - D_S \] (5.5)

and yields the probability that any two species drawn from a population represent different species classes.

Figure 5.1 depicts five hypothetical systems with 3, 4 or 5 species, labelled with S1 to S5. The absolute of each population is given; additionally the relative abundance of each species is shown. For each system, the absolute abundance is given between brackets. Table 5.1 additionally shows the species richness \( m \) and the aforementioned diversity indices \( D_{BP} \), \( D_{SW} \), \( E_{SW} \) and \( I_{SW} \).

System A and system B each have three species. The relative abundance of each species is the same: each species accounts for 33% of the relative abundance. Given that the relative abundance of each species is similar, diversity indices will be the same: the Shannon-Wiener diversity index amounts to 1.1, and given the fact that the each species is equally present in the system, system A and system B are considered to have a perfect diversity of 1. System C and system D contain one respectively two species more than system A and system B. Given that the relative abundance of these additional species is lower, this will result in a lower evenness and a lower Gini-Simpson index. This can be seen as counter-intuitive: a
5.3. Diversity in transport and urban planning

### Table 5.1: Examples of biodiversity indices based on a number of hypothetical systems

<table>
<thead>
<tr>
<th>Species</th>
<th>System A</th>
<th>System B</th>
<th>System C</th>
<th>System D</th>
<th>System E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>%</td>
<td>#</td>
<td>%</td>
<td>#</td>
</tr>
<tr>
<td>S₁</td>
<td>5</td>
<td>0.33</td>
<td>10</td>
<td>0.33</td>
<td>15</td>
</tr>
<tr>
<td>S₂</td>
<td>5</td>
<td>0.33</td>
<td>10</td>
<td>0.33</td>
<td>10</td>
</tr>
<tr>
<td>S₃</td>
<td>5</td>
<td>0.33</td>
<td>9</td>
<td>0.30</td>
<td>3</td>
</tr>
<tr>
<td>S₄</td>
<td>1</td>
<td>0.03</td>
<td>2</td>
<td>0.07</td>
<td>4</td>
</tr>
<tr>
<td>S₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>m</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>System Bp</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>$D_{SW}$</td>
<td>1.10</td>
<td>1.10</td>
<td>1.21</td>
<td>1.12</td>
<td>1.24</td>
</tr>
<tr>
<td>$E_{SW}$</td>
<td>1.00</td>
<td>1.00</td>
<td>0.87</td>
<td>0.81</td>
<td>0.77</td>
</tr>
<tr>
<td>$I_S$</td>
<td>0.71</td>
<td>0.69</td>
<td>0.71</td>
<td>0.65</td>
<td>0.67</td>
</tr>
</tbody>
</table>

A system with a higher species richness is less diverse than a system with a lower number of species. System E contains five species and has a total population of 60. Each species has a different relative abundance, resulting in Shannon-Wiener evenness of 0.77, the lowest of all five systems.

This section served as an introduction to measurement of diversity. The next section will continue with the application of these indices in transport and urban planning.

### 5.3 Diversity in transport and urban planning

#### 5.3.1 Diversity and land-use

Diversity indexes are found in a range of built environment and travel behavior studies. The most commonly applied diversity index is the Shannon-Wiener index, of which the usage in urban planning goes at least as far back as the work of Frank and Pivo (1994). Within urban planning, a certain number of land-uses is set equal to the number of species; the square footage per land-use within the system is set equal to the number of organisms. The entropy index can be calculated on many spatial scales, varying from traffic zones to buffers around dwellings. Variations exist in
which land-use categories are used. For instance, Cervero and Kockelman (1997) use the following land-use categories: residential, commercial, office, institutional, industrial, parks and recreation.

Several shortcomings of the usage of diversity indices have been pointed out by Hess et al. (2001). First, as with measures of density, the level of measurement (e.g. census tracts) might simply be too large to capture variations in travel behaviour. Second, the measure does not take into account spatial interaction of different uses. Third, the index weighs all categories of land-use equally: an area with office and industrial usage will have the same travel implications as an area with retail and residential usage. Brown et al. (2010) voice similar concerns and additionally highlight the issue of 'missing' land-uses: an entropy measure would not include land-uses not including in the calculation of the index: unscored areas. For instance, an area that contains residential, retail and industrial land usage will have the same entropy as an area with only residential and retail if the industrial land-usage is unscored and is not included in the calculation of the land-use mix. Frank et al. (2005) overcome this issue by dividing the proportion of each land-use over the total buffer area instead of dividing by the sum of land areas. To overcome the critique that a composite index fails to test the effect of the types of uses mixed, Rajamani et al. (2003) include distribution quotients in their models. These quotients are calculated as the ratios of the acreage in each land-use type to the number of housing units in the neighbourhood.

Another concern is brought forward by Manaugh and Kreider (2013); they question the fact that an even land-split is considered 'perfect'; a key point that lacks a theoretical basis. An area split 50/50 between two land-uses is considered better than an area split 60/40.

In addition to these points of critique there are three remaining issues to be highlighted.

When using the Shannon-Wiener evenness index to measure biodiversity, the index (numerator) is divided by the number of species in the system. For instance, system A and system B depicted in Figure [5.1] have the same evenness. However, in land-use studies the diversity index is commonly divided by the number of land-uses in the 'universe' and not by the number of land-uses in the area of interest. In the example provided in Figure [5.1] there would be 5 species in total, of which two species (species 4 and 5) are not present in system A and two species are not present in system B.
Furthermore certain land-uses are often included in the calculation of a land-use mix. One example is the inclusion of residential land-usage. An area split 50/50 between residential and retail might be considered as perfectly diverse, but it is questionable if 50% residential land-use is able to support 50% retail use.

Finally, dense urban environments are characterized by a mix of building heights and the presence of mixed-use buildings. A two-dimensional top-view of land-uses will not provide an accurate description of a true three dimensional mixed-use environment. For instance, a residential tower might only have a small footprint but have 30 stories. The question is whether to include the total floor area in the calculation of a land-use mix. This issue has not been addressed in the calculation of land-use mix indices.

5.3.2 Measuring needs: destination-based indices

The usage of common descriptions of land-use, such as residential, commercial and religion in diversity indices may be fueled by data availability on one hand and on other hand, the relevance of these descriptions for policy-makers and future land-use plans. These descriptions reflect their economic and social functions rather than their behavioral characteristics (Banerjee and Baer, 1984, p. 125). Descriptions of amenities, such as convenience store, supermarket, gas station and neighborhood park provide better descriptions of how individuals categorize, describe and use their environment.

A distinction can be made between accessibility measures summing the amenities within a pre-specified area and proximity measures, measuring the proximity to the nearest amenity of a certain type.

Kuzmyak et al. (2006) introduce a walk opportunities measure: \( WO = \sum_{O_{i=1}}^{O_{n}} W_i S_i / D_i \). This measure includes a destination value \( W_i \), a destination size \( S_i \) and a distance \( D_i \). Destination value is inherently a subjective concept. An early attempt to measure a destination value is provided by Banerjee and Baer (1984, p. 135-139). In this study, they ask respondents to rate the desirability for 80 neighbourhood elements. Desired elements included supermarkets and other types of stores, but also neighbourhood 'hardware', such as street lights, pedestrian crossings and bus stops. Kuzmyak et al. (2006) follow a similar approach and rate the importance and desirability
of destinations on four criteria: subsistence, measuring the importance of the activity to daily life, convenience, measuring the desirability to have an activity close at hand, entertainment, reflecting the contribution to quality of life and ambiance, reflecting the character of the activity.

Walk Score is a publicly available large-scale method for calculating walkability (WalkScore, 2016; Duncan et al., 2011). Data sources include Google, Open Street Map and Education.com. Amenities are divided into five categories: retail (groceries, books, clothes, hardware, drugs, musix), food (coffee shops, restaurants, bars), educational (schools), recreational (parks, libraries, fitness centers) and entertainment (movie theatres). Walk Score awards points based on the distance to the closest amenity in each category. If the closest amenity in a category is within 0.25 miles (or 0.4 km), the maximum number of points is assigned. The number of points declines as the distance approaches 1 mile (or 1.6 km). No points are awarded for amenities further than 1 mile. Each category is weighted equally and the points are summed and normalized to yield a score from 0 to 100. A newer version of Walk Score includes network distances and other indicators to measure pedestrian friendliness, such as intersection density and block size. Walk Score only measures if there is a single case for each category nearby and does not include size, intensity of usage or a destination weight. Also, the categories can be considered quite broad: a supermarket would be considered similar to a convenience store. Both amenities however clearly cover a different aspect of daily needs. It should be noted though, that Walk Score does capture a form of diversity.

Instead of compiling a composite index, Lee and Moudon (2006) measure the distance to 31 types of destinations and measure whether people walk for transportation purposes. The closer respondents were to a grocery store, a restaurant, a post office and a bank the more likely they were to walk.

Manaugh and El-Geneidy (2011) evaluate four walkability indices and their effect on the number of walking trips; they find that walkability indices, combined with household’s socio-demographics, correlated with walking trips, and that different walkability indices explain different trip purposes better. Frank and Ulmer (2013) evaluates the existing Walkscore and proposes to calibrate destination weights on the association of distance, socio-economic characteristics and measured exercise intensity.
5.4 Calculating diversity & local accessibility

5.4.1 Destination diversity and local accessibility

Destination diversity

As pointed out in the previous sections, many diversity indices consider an even distribution of species, land-uses or destination types perfect. One example is a diversity index applied by Rajamani et al. (2003). They apply the following diversity index:

\[
D_i = 1 - \left| \frac{LU_c}{T} - \frac{1}{4} \right| + \left| \frac{LU_r}{T} - \frac{1}{4} \right| + \left| \frac{LU_i}{T} - \frac{1}{4} \right| + \left| \frac{LU_o}{T} - \frac{1}{4} \right| \]

(5.6)

where \( D_i \) is the diversity of neighbourhood \( i \), \( LU_c, LU_r, LU_i, LU_o \) are commercial, residential, industrial and other land usages in a neighbourhood, \( T \) is the sum of these land-uses. While many authors state that this index varies between 0, for no land-use mix, and 1, this is not always the case. In this case specifically, if all land-uses would add up to 100% and for a particular area there is 100% of a single land-use the diversity indeed would be 0. However, if all land-uses do not add up to 100%, the minimum diversity would be higher. In this case, the diversity would vary between 0.33 and 1.

In this section a new diversity index is proposed, derived from the diversity index in Equation 5.7, which takes into account the desired amount of consumption of a certain activity instead of stating that an even distribution is perfect. The proposed destination diversity index is calculated as follows:

\[
DD_i = 1 - \sum_{k=1}^{k} \frac{\text{Min}(DA_k, A_{k,i})}{TDA} - \frac{DA_k}{TDA} \]

(5.7)

where \( DD_i \) is the destination diversity from origin \( i \), \( DA_k \) is the desired accessibility of opportunity \( k \), \( A_{k,i} \) is the actual accessibility of destination \( k \) from origin \( i \), \( \text{Min}(DA_k, A_{k,i}) \) is the minimum of the desired and actual accessibility and \( TDA \) is the total desired accessibility. In this case, the desired diversity will vary between 0 and 1, where 0 indicates no diversity.
and 1 indicates that all desired elements are present in the desired quantity.

The accessibility of destination $k$ is calculated as

$$A_{k,i} = \sum_{j=1}^{n} d_j f(c_{k,ij})$$

(5.8)

where accessibility $A_{k,i}$ of origin $i$ is the sum of destination weights $d$ multiplied by the generalized costs $c$ from travelling from origin $i$ to destination $j$, subject to cost function $f$ which can be specified for different destination types. The weights $d$ should be accounted for in the DA of destination type $k$.

The question arises how to determine the desired accessibility of a destination. One possibility is to set the number of destinations prescriptively and based on norms: every origin should have a daycare within 500 meters, there should be a certain number of convenience stores, etc. Alternatively, it is a possible to draw an analogue to sustainable and unsustainable ecosystem: within existing neighbourhoods the diversity can be quantified and set against indicators describing, among others, social diversity and mode share.

Also, it is important to note that the set of parameters describing a diverse environment needs not to be constant by location or individual. After all, a young family requires a different diversity of amenities as elderly; in a rural environment different expectations exists as in an urban environment.

This concept can be extended beyond desired accessibility, and can be used to describe desired land-use mix. If all land-uses add up to 100%, as is commonly the case in buffer-based analyses, it is necessary to introduce a denominator in Equation 5.6:

$$DD_i = 1 - \frac{\sum_{k=1}^{k} \frac{Min(DA_k, A_{k,i})}{TDA} - \frac{DA_k}{TDA}}{\frac{2(n-1)}{n}}$$

(5.9)

where the similar definitions hold as in equation . The additional $n$ refers to the number categories considered in the analysis.

In this case the accessibility of a destination is factored into equation 5.9 as it is believed that destinations that are located further away should
not contribute as much to the diversity of an area as destinations that are located nearby. However, the equation can also applied without taking into account the accessibility but simply the desired amount of land-use or the desired number of land-uses.

Local accessibility
For the calculation of local accessibility, Kuzmyak et al. (2006) propose a weighted accessibility index:

\[ W_{A_i} = \sum_{k=1}^{n} w_k A_{ki} \]  

(5.10)

where \( W_{A_i} \) is the weighted accessibility of origin \( i \), \( A_k \) is the accessibility to opportunity type \( k \), calculated as in Equation 5.12 and \( w_k \) is the weight for opportunity type \( k \).

The uneven distribution of opportunities per opportunity type raises the issue whether using the absolute number of opportunities yields the desired results. Therefore, it is again proposed to use a desired number of opportunities per opportunity type for a composite accessibility index:

\[ W_{A_i} = \sum_{k=1}^{n} w_k \text{Min}(DA_k, A_{k,i}) \]  

(5.11)

Nevertheless, when using separate weighted accessibility indices it might not be necessary to consider the desired accessibility.

Distance decay
The classic accessibility formulation as used for the calculation of macro-accessibility assumes the negative exponential function as widely used in literature. The choice of the impedance factor has a major influence on the accessibility of a destination. The question arises if a similar exponential impedance function should be used for non-motorized transport (Vale and Pereira, 2014). Vale and Pereira (2014) argue that individuals are not able to make an accurate estimation of travel times for shorter distances and/or might be indifferent to walks up to an acceptable distance. They propose a cumulative-gaussian impedance function.

Figure 5.2 shows several distance decay functions. A rectangular function as used in cumulative opportunity index, an exponential function with two
decay parameters (-0.1 and -0.2) and a cumulative gaussian distribution. The cumulative-gaussian function is specified as follows:

\[
A_i = \sum_{j=1}^{n} d_j f(c_{ij})
\]

where

\[
f(c_{ij}) = \begin{cases} 
1, & \text{if } c_{ij} \leq C \\
\exp \left( \frac{c_{ij} - C}{v} \right), & \text{if } c_{ij} > C 
\end{cases}
\]

where the generalized costs are \( c \) for travelling from origin \( i \) to destination \( j \). When the travel costs are lower than cost threshold \( C \) the travel costs are set to 1, giving the destination it’s full weight. When travel costs exceed \( C \) destination weight is multiplied by a number between 0 and 1. The parameter \( v \) determines the slope of the cost function. For this section we set the cost threshold to 5 minutes walking and assume a walking speed of 4 kilometres per hour. Parameter \( v \), determining the steepness of the decay function, is also to be determined by the analyst and is set to 50 for this study.

### 5.4.2 Data sources

Destinations have been gathered from three main sources.

Points of interest have been obtained via the Google Places API (Google, 2015) for both Singapore and Switzerland. Google Places has been selected after evaluating several alternative point of interest databases. A selection has been made based on the throttle limit of the point of interest database, an estimate of the completeness of the database as well as the taxonomy of points of interest. Land-use for Singapore has been taken from URA’s Masterplan 2012 (see also chapter 2). Google Places contains a wide range of categories. Each place can be assigned a number of categories. For instance, a pharmacy ideally is categorized as pharmacy, store, health, point of interest, establishment and a gas station combined with convenience store might be categorized as grocery or supermarket, food, store, gas
station, point of interest, establishment. This closer inspection revealed that some local knowledge is required, especially for retrieving supermarkets and convenience stores and pharmacies. For these three categories an additional manual data categorization based on chain name was performed.

Transit stops in Switzerland have been obtained from the Swiss GTFS feed (geOps, 2015). This feed makes a distinction between the different transit modes present in Switzerland and provides the location of each transit stop. Transit stops have been obtained from the Singaporean Land Transport Authority.

Schools in Singapore and Switzerland have been sourced from online databases (Ministry of Education, 2015; Educa, 2015); the location has been subsequently geo-coded. We make a distinction the following education levels: primary schools and secondary schools.

These points of interest have been grouped into six categories; these categories and the number of points of interest are reported in Table 5.2.

From this enumeration it becomes clear that certain groups are lacking. Examples include for instance child care centres, or playgrounds. Furthermore, other basic amenities like butchers and vegetable stores seem to be lacking as well. This is recognized as a shortcoming. Nevertheless, the
Table 5.2: Points of interests for the calculation of diversity and destination indices

<table>
<thead>
<tr>
<th>Point of interest (group)</th>
<th>Description</th>
<th>Singapore</th>
<th>Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily needs</td>
<td>Supermarkets, convenience stores and bakeries</td>
<td>4,100</td>
<td>5,300</td>
</tr>
<tr>
<td>Other stores</td>
<td>Bicycle stores, hardware stores, department stores, shoe stores, book stores, pet stores, lock smiths, personal care, jewellery stores, clothing stores, florists</td>
<td>33,400</td>
<td>51,300</td>
</tr>
<tr>
<td>F&amp;B, culture, entertainment</td>
<td>Museums, art galleries, movie galleries, cafes, bars, restaurants, and bowling alleys</td>
<td>14,700</td>
<td>33,600</td>
</tr>
<tr>
<td>Healthcare</td>
<td>Dentists, hospitals, doctors, physiotherapists, pharmacies</td>
<td>3,000</td>
<td>30,100</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td>400</td>
<td>4,800</td>
</tr>
<tr>
<td>Parks, religion</td>
<td>Parks, places of worship</td>
<td>1,300</td>
<td>5,900</td>
</tr>
<tr>
<td>Public transport</td>
<td></td>
<td>4,700</td>
<td>26,600</td>
</tr>
<tr>
<td>Excluded (other point of interest types)</td>
<td>Uncategorised stores, car related, government offices</td>
<td>20,600</td>
<td>22,600</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>82,200</td>
<td>180,200</td>
</tr>
</tbody>
</table>

proximity of one of these points of interest is highly likely to correlate with the presence of other stores.

The desired quantities have been partially been based on the presence of the number of records in the data set. For instance, a supermarket or convenience store occurs less often than a records in the category 'other stores’. On other hand, the desired quantity has seen set higher if the category is contains many subcategories, as is the case for ‘other stores’. For the category ‘daily needs’ the desired quantity is set to 2.5; for the category ‘daily needs’ the desired quantity is set to 0.5; for F&B, culture & entertainment the desired quantity is set to 5; for the category ‘other stores’ the quantity is set to 10; and for the category ‘education’ the desired quantity is set to 1.5.
5.4.3 Calculation of land-use mix

The land-use mix for Singapore has been calculated using the aforementioned Shannon-Wiener evenness index. Several variants of this land-use mix have been calculated using URA’s Masterplan.

The following considerations were made when developing the calculation procedures for the land-use mix:
- The set of locales for which to calculate the surrounding land-use mix.
- Whether the land-use mix within the locale should be calculated or surrounding the locale.
- Whether the outline of the locale should be used or if the centroid should be used.
- A surface of geometries containing different land-uses, land-use descriptions and a land-use weight.

Figure 5.3: URA Masterplan 2012 with two areas highlighted (a) Little India (b) Serangoon Gardens. Note the difference in scale.

This index was calculated for approximately a thousand areas in Singapore; the outcome for two distinctly different areas will be shown. Little India is an area that is well-known to residents and tourists alike and is characterised by mainly commercial and residential zoning (Figure 5.3a).
Serangoon Gardens is located in the north-east of Singapore and is characterised by a small centre that contains a selection of shops, a popular food centre, a park, and several schools and residential streets with semi-detached housing. Figure 5.3b highlights the planned land-use for the Serangoon Gardens. This area is split into different zones.

**Figure 5.4:** Diversity excluding residential land-use in (a) Little India (b) Serangoon Gardens.

Different land-use types can be considered when calculating diversity. Figure 5.4a and Figure 5.4b highlight the results if the land-use types of commercial, business, religious, and park are included in the calculation of diversity. To enable easy comparison of the results, the numbers represent percentiles. Serangoon Gardens ranks 10th, whereas Little India ranks between 5th and 6th. These percentile rankings reveal that 90% of the areas rank lower than 10. If residential land usage is added to the calculation (Figure 5.5a and Figure 5.5b), Little India ranks 8th, whereas the Serangoon Gardens ranks between 5th and 10th, depending on the area of residential space in the zone.

**Calculation of accessibility**

To calculate destination diversity and weighted accessibility the accessibility to a wide range of destinations is required. For this a program was written...
in the programming language Java. The program relies on the Geotools libraries (Geotools, 2016) for the reading and writing of spatial data, a graph library for routing (Jgrapht, 2016), and the Spring framework for program configuration (Spring, 2016).

The calculation procedure takes into account a set of origins for which to calculate the local accessibility. These origins can vary from buildings, a raster or for instance activity locations of survey respondents. These start locations can be specified as points or polygons; additionally, it can be specified whether to use the centroid of the polygon or the hull.

Second, a set of destinations, or opportunities is required. A set of activity opportunities, with a unique identifier, category and weight. The identifier will be used to match the activity opportunity to a location. This set of locations, has a unique identifier and a geometry. To optimize computation time activity opportunities can be aggregated to locations prior to computation. For instance, a shopping mall might contain more than 50 activity opportunities.

If generalized costs from origins to destinations are required by the analyst, a network needs to specified, which can be a set of lines. An
attribute field specifying the costs of a link can be specified if this is wished for.

Finally, a set of parameters needs to be set. These include the maximum size of the subgraph to be used for the routing and the maximum snapping distance for origins and locations to the network. Additionally, the analyst can specify the number of links origins and destinations need to be snapped to.

The analyst can also specify the desired accessibility metrics a user wants to calculate. The computation intensive part of the calculation of local accessibility is the routing between any given origin and a set of destinations. Transforming distance by means of a distance decay function is not ‘cheap’. Currently, several functions are implemented: the rectangular function, the exponential function and a combined rectangular-gaussian function. It is possible to calculate any number of these distance transformations. As a bonus, the nearest activity opportunity is calculated, as this is results from the routing. The routing can easily be parallelized as it involves 1-to-n routing without assignment of flows. It is possible to specify the number of cores to be used in the computation.

The computation results in three output datasets: (1) a dataset containing the origins and the accessibility score per destination category and the specified computations, (2) the network edges used for routing and (3) the network vertices. Destination categories are automatically aggregated from the input data. The latter two datasets are optional and were used for debugging purposes.

Initially, the toolbox was envisaged to use flexible input and output data sources (e.g. shapefiles, text files) and use was made of Geotools functionality allowing for the usage of different files. The production version of the code uses PostgreSQL as input and output. Computation for Singapore (160,000 origins, 20,000 locations and 70,000 destinations) takes less than 15 minutes; computation for Switzerland (76,000 origins and 180,000 destinations) has been executed as well in similar times. Two examples are highlighted in Figure 5.6 and Figure 5.7, where the diversity of Singapore respectively Switzerland is shown for each hectare (100m grid).

Any desired diversity and weighted accessibility metric can be calculated after the calculation procedure using the computed accessibilities to the different destinations.
Figure 5.6: Desired diversity index for the Canton of Zurich
5.5 Application: choice to walk in Singapore and Switzerland

Six opportunity types are considered: daily needs (this includes supermarkets, convenience stores and pharmacies), other types of stores, parks and religion, healthcare, entertainment (aggregated from culture and night entertainment) and education. Except for education locations, Google Places opportunities are used and categorized to one of the 6 remaining opportunity types.

A series of binomial models describing the choice whether to walk have been estimated for different trip purposes: home-based work (HBW), home-based leisure (HBL), home-based shopping (HBS), home-based shopping / leisure (HBL/S), home-based education (HBE), work-based leisure (WBL), work-based shopping (WBS) and work-based shopping / leisure (WBS / L).
Appendix F.2 provides more background information on the MNL model. Model results for Switzerland are shown in Table 5.3; model results for Singapore are shown in Table 5.4. For both countries the diversity index as well as a walk index by destination category has been entered into the utility function; no socio-demographic variables were included.

For Switzerland, the constructed indices best describe the choice whether to walk to work: an increasing diversity leads to a higher propensity to go by foot, as well as the proximity to daily needs, education, restaurants & entertainment. The second best model for Switzerland is the model that describes whether to go by foot from home to shop. As compared to the HBW model we find that the presence of shops providing daily needs are more important, as is the presence of schools. Surprisingly, the proximity to other shops is perceived as negative. Also, the diversity of these six categories within 300 meters is considered to be more important as for HBW trips. For HBE walking trips the proximity to schools is the most important factor. WBL trips are more likely to be made by foot in a diverse environment. Whether a WBS trip is conducted on foot depends on the proximity of shops serving daily needs; again ‘other stores’ negatively influence whether a trip is made by foot.

The parameter estimates for Singapore are shown in Table 5.4. Except for HBE trips, we find diversity not to be significant when explaining trips by foot. Home-based leisure and shopping trips are more likely to be made by foot if shops serving daily needs, education and other store are present. Work-based shop and leisure trips are more likely to made by foot if daily needs are in proximity. Other stores, and surprisingly health care facilities, reduce the probability of a trip being made by foot.

Aggregate-level elasticity effects are presented in Table 5.5 and Table 5.6 for Switzerland and Singapore respectively. The calculation procedure for these elasticities is outlined in Appendix F.2. For Switzerland, elasticity values indicate that diversity had the most impact on home-based work trips and work-based leisure trips. In contrast, diversity had the least impact on home-based leisure trips. Overall, the individual destination indices have a smaller influence on the propensity to walk. The proximity to shops providing daily needs have the largest influence, whereas the proximity of restaurants and entertainment only has a marginal influence. Elasticity values for population density and employment density are marginal, except for work-based shop trips.
Table 5.3: Walk choice models by trip purpose for Switzerland

<table>
<thead>
<tr>
<th></th>
<th>HBW (Est (t-test))</th>
<th>HBS (Est (t-test))</th>
<th>HBL (Est (t-test))</th>
<th>HBE (Est (t-test))</th>
<th>WBS (Est (t-test))</th>
<th>WBL (Est (t-test))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 6 and 10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.33 (29.47)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Between 10 and 14</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.48 (23.12)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Between 14 and 18</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.28 (11.56)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Between 18 and 35</td>
<td>-0.9 (-9.48)</td>
<td>-0.23 (-3.61)</td>
<td>-0.523 (-16.74)</td>
<td>-</td>
<td>0.249 (3.4)</td>
<td></td>
</tr>
<tr>
<td>Between 35 and 50</td>
<td>-0.661 (-7.24)</td>
<td>-0.236 (-4.48)</td>
<td>-0.128 (-4.79)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Between 50 and 65</td>
<td>-0.354 (-3.9)</td>
<td>-0.126 (-2.49)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Over 65</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>-0.299 (-6.72)</td>
<td>-0.129 (-3.23)</td>
<td>-0.285 (-13.55)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mobility tools</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car and driving license</td>
<td>-0.455 (-8.25)</td>
<td>-0.785 (-18.59)</td>
<td>-0.142 (-6.2)</td>
<td>-</td>
<td>-0.701 (-6.85)</td>
<td>-0.174 (-1.98)</td>
</tr>
<tr>
<td><strong>Built environment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-</td>
<td>-</td>
<td>-0.00712 (-2.48)</td>
<td>0.0681 (8.12)</td>
<td>-</td>
<td>0.0161 (1.91)</td>
</tr>
<tr>
<td>Employment density</td>
<td>0.0147 (1.84)</td>
<td>0.0337 (3.49)</td>
<td>-0.0173 (-3.75)</td>
<td>-</td>
<td>-0.0211 (6.33)</td>
<td></td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination diversity</td>
<td>1.91 (11.3)</td>
<td>1.34 (12.55)</td>
<td>0.524 (9.3)</td>
<td>0.833 (5.35)</td>
<td>1.59 (8.5)</td>
<td>1.14 (8.89)</td>
</tr>
<tr>
<td><strong>Walk indices</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily needs</td>
<td>-</td>
<td>0.0466 (11.84)</td>
<td>-</td>
<td>-</td>
<td>0.0344 (5.87)</td>
<td>-</td>
</tr>
<tr>
<td>Other stores</td>
<td>-0.00408 (-2.95)</td>
<td>0.00386 (2.22)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Food &amp; entertainment</td>
<td>0.00437 (3.47)</td>
<td>-0.0105 (-7.11)</td>
<td>0.00359 (5.89)</td>
<td>-</td>
<td>-0.00347 (-3.15)</td>
<td>-</td>
</tr>
<tr>
<td>Parks &amp; religions</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Education</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.501 (7.15)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Healthcare</td>
<td>-</td>
<td>-0.00246 (-2.32)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>-1.79 (-15.47)</td>
<td>-0.569 (-13.55)</td>
<td>0.0889 (3.73)</td>
<td>-2.82 (-25.48)</td>
<td>-1.23 (-11.7)</td>
<td>-0.959 (-9.95)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>18,042</td>
<td>14,042</td>
<td>37,925</td>
<td>6,794</td>
<td>2,628</td>
<td>3,592</td>
</tr>
<tr>
<td><strong>Chosen</strong></td>
<td>2,531</td>
<td>8,992</td>
<td>17,435</td>
<td>2,945</td>
<td>933</td>
<td>1,648</td>
</tr>
<tr>
<td><strong>Adjusted rho-square</strong></td>
<td>0.441</td>
<td>0.174</td>
<td>0.02</td>
<td>0.201</td>
<td>0.203</td>
<td>0.084</td>
</tr>
</tbody>
</table>
Table 5.4: Walk choice models by trip purpose for Singapore

<table>
<thead>
<tr>
<th></th>
<th>HBW Est (t-test)</th>
<th>HBS/L Est (t-test)</th>
<th>HBE Est (t-test)</th>
<th>WBS/L Est (t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 6 and 10</td>
<td>-</td>
<td>-</td>
<td>3.38 (15.57)</td>
<td>-</td>
</tr>
<tr>
<td>Between 10 and 14</td>
<td>-</td>
<td>-</td>
<td>2.87 (13.3)</td>
<td>-</td>
</tr>
<tr>
<td>Between 14 and 18</td>
<td>-</td>
<td>-</td>
<td>1.34 (6.06)</td>
<td>-</td>
</tr>
<tr>
<td>Between 18 and 35</td>
<td>-0.796 (-7.09)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Between 35 and 50</td>
<td>-0.37 (-3.72)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Between 50 and 65</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Over 65</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>-0.952 (-10.38)</td>
<td>-0.338 (-4.5)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mobility tools</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car and driving license</td>
<td>-0.95 (-6.94)</td>
<td>-1.3 (12.3)</td>
<td>-</td>
<td>-0.416 (-2.64)</td>
</tr>
<tr>
<td><strong>Built environment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-</td>
<td>0.0138 (5.79)</td>
<td>0.022 (9.81)</td>
<td>0.0269 (5.19)</td>
</tr>
<tr>
<td>Employment density</td>
<td>0.0279 (2.32)</td>
<td>0.06 (4.66)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination diversity</td>
<td>0.583 (3.7)</td>
<td>0.253 (1.91)</td>
<td>-</td>
<td>0.805 (3)</td>
</tr>
<tr>
<td><strong>Walk indices</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily needs</td>
<td>-</td>
<td>0.0244 (5.73)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other stores</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.00275 (5.93)</td>
</tr>
<tr>
<td>Food &amp; entertainment</td>
<td>-</td>
<td>-0.00425 (-3.02)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parks &amp; religions</td>
<td>-</td>
<td>-0.0222 (-1.82)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Education</td>
<td>-</td>
<td>-</td>
<td>0.278 (7.27)</td>
<td>-</td>
</tr>
<tr>
<td>Healthcare</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>-2.44 (-25.44)</td>
<td>-0.873 (-8.43)</td>
<td>-4.69 (-20.06)</td>
<td>-1.16 (-7.83)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>12,272</td>
<td>4,109</td>
<td>6,855</td>
<td>942</td>
</tr>
<tr>
<td><strong>Chosen</strong></td>
<td>593</td>
<td>1,869</td>
<td>1,789</td>
<td>461</td>
</tr>
<tr>
<td>Adjusted rho-square</td>
<td>0.742</td>
<td>0.09</td>
<td>0.304</td>
<td>0.128</td>
</tr>
</tbody>
</table>
For Singapore, approximately the same elasticity values similar trends can be observed. A notable difference is the elasticity value of population density for home-based education trips, which is higher than in Switzerland. Elasticity values for diversity are slightly lower, especially for home-based shop trips.

Table 5.5: Choice to walk: direct aggregate-level elasticity effects for Switzerland

<table>
<thead>
<tr>
<th></th>
<th>HBW</th>
<th>HBS</th>
<th>HBL</th>
<th>HBE</th>
<th>WBS</th>
<th>WBL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-</td>
<td>0.047</td>
<td>-0.017</td>
<td>0.127</td>
<td>-</td>
<td>0.047</td>
</tr>
<tr>
<td>Employment density</td>
<td>0.055</td>
<td>0.110</td>
<td>-0.022</td>
<td>-</td>
<td>-</td>
<td>0.110</td>
</tr>
<tr>
<td>Diversity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination diversity</td>
<td>0.513</td>
<td>0.240</td>
<td>0.048</td>
<td>0.053</td>
<td>0.387</td>
<td>0.240</td>
</tr>
<tr>
<td>Walk indices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily needs</td>
<td>-</td>
<td>0.123</td>
<td>-</td>
<td>-</td>
<td>0.351</td>
<td>-</td>
</tr>
<tr>
<td>Other stores</td>
<td>-0.119</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Food &amp; entertainment</td>
<td>0.114</td>
<td>-0.083</td>
<td>0.0284</td>
<td>-</td>
<td>-0.115</td>
<td>-</td>
</tr>
<tr>
<td>Parks &amp; religions</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Education</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.0444</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Healthcare</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

5.6 Conclusion

This chapter has evaluated the measurement of diversity and local accessibility. Diversity measures used in urban and transport planning mainly stem from ecology; an even distribution of species is considered to be perfect. Despite the criticism voiced on this fact, no alternative diversity index is proposed. This chapter proposes a diversity index that includes a desired accessibility; if this desired accessibility is exceeded, it will not be accounted for in the diversity index.

For the calculation of diversity and local accessibility use have been made of a publicly available online points of interest database and road networks. The underlying software can easily be used with other data sources.
Table 5.6: Choice to walk: direct aggregate-level elasticity effects for Singapore

<table>
<thead>
<tr>
<th></th>
<th>HBW</th>
<th>HBS/L</th>
<th>HBE</th>
<th>WBS / L</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-</td>
<td>0.256</td>
<td>0.541</td>
<td>0.126</td>
</tr>
<tr>
<td>Employment density</td>
<td>0.108</td>
<td>0.100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination diversity</td>
<td>0.177</td>
<td>0.036</td>
<td>-</td>
<td>0.181</td>
</tr>
<tr>
<td><strong>Walk indices</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily needs</td>
<td>-</td>
<td>0.202</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other stores</td>
<td>0.132</td>
<td>-</td>
<td>-</td>
<td>0.207</td>
</tr>
<tr>
<td>Food &amp; entertainment</td>
<td>-</td>
<td>-0.058</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parks &amp; religions</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Education</td>
<td>-</td>
<td>-</td>
<td>0.204</td>
<td>-</td>
</tr>
<tr>
<td>Healthcare</td>
<td>-</td>
<td>-0.039</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Surprisingly, for both Singapore and Switzerland it was found that evaluating diversity based on a cumulative gaussian distance decay function resulted in counter-intuitive and negative parameter estimates for diversity. When including adjusting the diversity index to only account for the number of opportunities reached within 300 meters network distance parameter estimated were significant and carried the expected sign. It is mainly thought that this is due to the decay not being steep enough in the cumulative gaussian function. This finding calls for further investigation of the usage of diversity indicators for different distance bands.

Manaugh and El-Geneidy (2011) had shown that for different household types different accessibility indices were more significant; however, these walkability indices were composite indices and did not provide a breakdown per amenity type. The choice to walk is dependent on trip purpose and accessibility indices containing different amenity types. For instance, home-based and work-bases shopping trips are more likely to be made by foot when supermarkets, bakeries and convenience stores are within easy reach. For Switzerland, home-based and work-based leisure trips are not well explained by the different accessibility indices. Lee and Moudon (2006) reached a similar conclusion when evaluating walking for transport purposes versus walking for recreational purposes. The latter was more
influenced by the presence of sidewalks, and architectural visual quality, whereas walking for transport was correlated with the presence of amenities. Interestingly, they found that the presence of hills correlated positively with recreational walking and negative with walking for transport. For this, either more data collection is required (i.e. parks, network length) or a further breakdown of the activity type 'leisure' should be investigated. This shows that it is necessary to use different weights per trip purpose, in addition to socio-economic classification proposed by Frank and Ulmer (2013).

In the previous chapter the usage of a pedestrian network generation algorithm was proposed and applied for large-scale accessibility calculations. It was chosen not to continue with the usage of such a detailed pedestrian network in this chapter, but to use road centrelines to represent the pedestrian network. Furthermore, only distance has been used as input for the routing algorithm. Wibowo and Olszewski (2005) studied mode choice for trips to MRT stations in Singapore. The study identified distance to be the most significant factor influencing mode choice, but also quantified that crossing a road is perceived as much as an additional distance of about 55m and climbing an overhead bridge was perceived as 90m distance. By combining the calculation procedures outlined in this chapter and the previous chapter such perceived distances can be incorporated in local accessibility calculations. This remains for future work.

Evaluating indices of a city and accompanying provides insights into the usage of space based on openly available data sources. However, these top-down images do not take away the need to verify these figures with ground-truths and certainly do not describe the character of an area. Similar to the conclusion when using pedestrian network generation it is advocated that top-down desktop analysis should go hand in hand with bottom-up field work.
Chapter 6

Vehicle ownership & usage in Switzerland and Singapore

This chapter is based on van Eggermond et al. (2016)

6.1 Introduction

Despite the fact that car ownership and vehicle miles travelled are reaching saturation in developed countries, vehicle ownership remains a factor in transport planning and modelling to be reckoned with (Kühnimhof et al., 2013). For instance, in Switzerland, only 20% of the households does not own a car and 80% of the persons possessing a driving license always have a car available. Statistics such as these highlight the relevance of understanding vehicle ownership and usage in the age of peak car.

In Switzerland there is an active societal debate to which extent existing urban areas can be further densified or if densification should take place in the urban fringe, and which form this densification should take (Hollenstein, 2014; Reuss, 2014).

Among others, densification will lead to a lower energy usage per capita due to efficiency gains and a higher share of trips made by active modes and public transport. The latter argument is spurred by the well-documented relationship between built environment and travel behaviour (e.g. Ewing and Cervero, 2010). However, inferring general conclusions from different studies remains a challenge. Zegras (2010) points out several
of these challenges: scales of analysis differ, built environment measures vary, the travel behaviour data used varies, control variables employed differ and the ultimate outcomes measured are different. Finally, a debate exists whether individuals self-select themselves: individuals may choose a residential location in line with their travel preferences (e.g. Cao et al., 2009) and whether this self-selection matters when measuring travel behavior outcomes of residential location choice (e.g. Naess, 2009).

As outlined in Chapter 2, Singapore is a small city state in Southeast Asia with a land area of 712 km$^2$, a permanent residential population of 3.77 million and a total population of 5.08 million in 2010, compared to respectively 697 km$^2$, 3.27 million and 4.03 million in 2000. GDP per capita amounts to S$ 59,813 (US$ 45,200, 2010), which makes it one of the wealthiest countries in Asia. Together with the increasing population and wealth, vehicle ownership has increased. The number of cars has increased from 392,961 in 2000 to 597,746 in 2010, or from 1 car per 10 households in 2004 to 1 car per 8.8 households in 2008 (Choi and Toh, 2010). The total number of motorized vehicles is close to 1 million. A set of policies has been put in place to curb vehicle ownership and usage, both to restrict the number of vehicles and the usage of vehicles.

Due to the high cost of vehicle ownership and their increasing wealth, Singaporeans tend to use their car intensively, resulting in negative externalities, such as noise and fine-particle emissions and dropping average speeds. The mode share of public transport has fallen between 1998 and 2008 from 63% in 1998 to 56% in 2008. The absolute number of public transport trips (excluding taxi) has increased from 4.33 million in 2000 to 5.37 million in 2010.

The relationship between vehicle ownership, usage and the built environment has been studied in areas worldwide (e.g. Potoglou and Kanaroglou, 2008; Li et al., 2010; Van Acker and Witlox, 2010; Zegras, 2010; Cao and Cao, 2013; Guerra, 2014). An earlier mobility tool ownership model for Switzerland (Ciari et al., 2007) mainly contained taste preferences based on the Swiss Microzensus, the five-yearly household travel survey (Bundesamt für Statistik BFS and Bundesamt für Raumplanung ARE, 2012). Among others, the model revealed distinct preferences for mobility tool ownership between German and French-speaking parts of the country.

In the context of the ongoing debate about further densifying in Switzerland the role of built environment on vehicle ownership levels and usage
is investigated. A series of built environment measurements is compared against Singapore’s vehicle ownership patterns.

A further literature review on vehicle ownership modeling is provided in section 6.2. Relevant data sources and descriptive statistics are presented in section 6.3. This chapter makes use of the Singaporean and Swiss travel survey, the accessibility measures presented in Chapter 3 and the diversity measures presented in Chapter 5. In section 6.4, the model results are presented and discussed. Section 6.5 provides a conclusion and an outlook.

6.2 Vehicle ownership, usage and built environment

6.2.1 Vehicle ownership and usage

Vehicle ownership influences both the range of daily travel decisions and long-term decisions. de Jong et al. (2004) provide a comprehensive review of aggregate and disaggregate vehicle ownership models up to 2002.

Lerman and Ben-Akiva (1976) introduced discrete choice models to automobile ownership. In disaggregate models the number of cars owned by a household can either be represented as an ordinal or nominal variable resulting in ordered or unordered choice models respectively. Ordered models assume that households prefer to own more vehicles; unordered models assume that households will choose the number of vehicles that maximizes their utility. Both model types can be found in literature to model vehicle ownership; Potoglou and Kanaroglou (2008) provide a summary of studies applying disaggregate models. Potoglou and Susilo (2008) compare three model types: Multinomial Logit (MNL) models, Ordered Logit (ORL) models and Ordered Probit (ORP) models in three regions. The outcome of their comparison showed that MNL models should be preferred to the ORL and ORP model.

More recently, several discrete continuous model approaches have been developed and applied to vehicle ownership and usage (Bhat and Sen, 2006; Fang, 2008; Liu et al., 2014). Anowar et al. (2014) discusses these recent model advances, and alternative approaches to vehicle ownership and usage models. Loder and Axhausen (2017) have applied a probit-based model for mixed types of outcomes in a model of car and season ticket ownership and
the number of car, public transport and non-motorized trips for Switzerland.

This chapter estimates static disaggregate ownership models; the household is the basis unit of analysis and the number of vehicles as choice. A separate regression model is estimated to obtain insight in relevant variables for vehicle usage.

### 6.2.2 Travel behaviour and the built environment

A mixed density index (MDI) and a land-use entropy index (EI) were included in models estimating vehicle ownership in Hamilton, Canada (Potoglou and Kanaroglou, 2008; Chu, 2002). The MDI is based on the employment and residences per acre per traffic zone; EI is the proportion of developed land in different land-use types within a 500 meter radius of the household. Both indexes have negatively effected car ownership. Zegras (2010) finds that households living in neighbourhoods with a high diversity, defined by land-usage, have a lower likelihood owning one or more vehicles. Guerra (2014) finds that households residing in census tracts with a higher diversity, travel more vehicle kilometres. Li et al. (2010) measure urban form by four attributes: population density at the subdistrict level within the city, distance from the household residential location to the central business district, distance from the residential location to the nearest bus stop, residential location within Beijing’s fourth ring road, which is the city’s urban fringe. They find that households tend to have fewer private cars when they live further away from the urban centre and indeed mention that result is opposite to what has been found in the developed world. Also, they find that households living within Beijing’s fourth ring road have a higher probability to own a car. While the authors do not mention this explicitly, it might that affluent households live closer to the city centre, but also that public transport is well developed in regions further from the CBD.

### 6.3 Data & descriptive analysis

### 6.3.1 Behavioural data & household characteristics

As a basis for vehicle ownership in Switzerland the data from the Swiss Travel Survey (Swiss Mikrozensus Verkehr) 2010 (Bundesamt für Statistik
BFS and Bundesamt für Raumplanung ARE (2012) is taken. In this travel behaviour survey 59,971 households and 62,868 persons were surveyed on topics ranging from ownership of vehicles, driving licenses and public transport subscriptions as well on vehicle usage and daily travel behaviour. For each household member demographics such as age and driving license ownership are available. Dependent on household size, one or two household members above 6 years old are interviewed on their travel behaviour of a single. This survey design yields a high number of households, but provides less information on number of employed persons per household and total daily distance travelled per household and per household member.

For Singapore, vehicle ownership and household information are available from the Household Interview Travel Survey (HITS) 2012. For this survey over 32,000 persons from over 9,000 households have reported their travel behavior on a single workday. The survey is conducted once every four years and is commissioned by the Singaporean Land Transport Authority (LTA). HITS contains data on three levels of aggregation. The highest level of aggregation contains household characteristics such as dwelling type, postal code and quantity and type of vehicle available. Second, person characteristics are available such as age, income, profession and employment type. On the lowest level of aggregation information on trips is available such as mode, purpose, cost and time.

Car ownership in Singapore is low: analysis reveals that 63% of the households do not own a car, and 31% owns a single vehicle. In Switzerland, only 20% of the households does not own a car and 80% of the persons possessing a driving license always have a car available.

The number of vehicles owned in Singapore and Switzerland is shown in Figure 6.1; the relationship between driving license and vehicle ownership is visualized in Figure 6.2. Households in Switzerland with a driving license are more likely to own a car than in Singapore. This relationship is more pronounced if the number of driving licenses increases.

The relationship between household income and vehicle ownership is visualized in Figure 6.3; households refusing to reveal income were excluded from this analysis. Overall monthly household income levels in Singapore are lower than in Switzerland. In both countries it can be seen that a higher household income results in higher vehicle ownership.
6.3.2 Accessibility & diversity

Population and job density

The Swiss Federal Office for Statistics provides data sets describing the population and the number of jobs for each hectare grid cell of the country (Bundesamt für Statistik BFS, 2014). Both population and job density has been calculated within a 400, 800 and 1200 meter radius of the household.

The relationship between job density, population density and vehicle ownership is visualized in Figure 6.4. Overall density levels in Singapore are higher than Switzerland overall. In the previous chapter it could be seen that in Switzerland the propensity to own a vehicle decreases if job and population density increases; this relationship is not clear in this figure due to axes limits. In Singapore a similar trend can be observed for population density; when population density increases, vehicle ownership is lower. This coincides with the high density public housing in Singapore. The
6.3. Data & descriptive analysis

Figure 6.2: Vehicle ownership and driving license holding in Singapore and Switzerland

relationship between employment density and vehicle ownership is not as clear in Singapore.

Figure 6.5: illustrates the relationship between the distance to a selected set of amenities. The proximity to any of these amenities does not seem to influence the propensity to own a vehicle.

Intersection density
Intersection density frequently features in travel behaviour studies. A high intersection density can shorten access distances and provide more route options. Intersections have been derived from OpenStreetMap; the density within 400 meters, 800 meters and 1200 meters is calculated.

Regional accessibility
Macro-accessibility is calculated by means of an Hansen-based accessibility measure:
Figure 6.3: Vehicle ownership in Singapore and Switzerland and household income (USD, excluding households refusing to reveal income)

\[ A_i = \sum_{j=1}^{n} d_j \exp(\alpha t_{ij}) \]  

(6.1)

where \( A_i \) is the total accessibility of zone \( i \), \( d_j \) are the opportunities at destination \( j \), \( \alpha \) is the distance decay (impedance) parameter and is the total travel time between \( i \) and \( j \). In this case, the distance decay parameters estimated for Switzerland and Singapore are taken from chapter 3.

Figure 6.6 depicts the influence of macro-accessibility on vehicle ownership. Quintiles are calculated per mode of transport to normalize between modes. Households not owning a vehicle tend to live in a zone with a high public transport accessibility. A decreasing trend can be observed: as the
Figure 6.4: Vehicle ownership, population density and job density in Switzerland and Singapore

![Graph showing vehicle ownership, job density, and population density in Switzerland and Singapore.]

Number of vehicles increases, public transport accessibility decreases.

The accessibility by public transport for Singapore and Switzerland is shown in Figure 6.6; a different distance decay parameter has been used for Switzerland.

The constructed walk index for Singapore and Switzerland is shown in Figure 6.7. In Switzerland a pattern can be observed between households living in areas with a higher walkability tending to own less vehicles. In Singapore this effect is less pronounced.
Figure 6.5: Vehicle ownership & network distance to selected amenities within 1250 meters

6.4 Results

6.4.1 Vehicle ownership in Switzerland & Singapore

MNL specification
Variables have been entered in a step-wise fashion to a constant only model. Variables representing discrete variables, such as the number of driving
licences and household size have been added as both continuous variable and as discrete variables representing groups. Variables were combined within alternatives and between alternatives when they were not significant per alternative. All model estimations have been performed with Biogeme (Bierlaire, 2003).

**MNL results: Switzerland**

Table 6.1 shows the model predicting functional vehicle ownership for households. All estimates are versus the alternative of owning no vehicle. The variables mostly carry the expected sign and are statistically significant.

Monthly household income is positive and increases in magnitude across alternatives; a higher incomes increases the probability of owning multiple vehicles. Variables representing household structure reveal different preference structures for each alternative. In the model specification a differentiation was made between young children (from birth to 10) and teenagers (11 years old or over). Having one young child decreases the utility of one vehicle. This can be because activity spaces are still small.
Table 6.1: Switzerland: vehicle ownership model

<table>
<thead>
<tr>
<th></th>
<th>0 vehicles</th>
<th>1 vehicle</th>
<th>2 vehicles</th>
<th>3 vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Est. (t-test)</td>
<td>Est. (t-test)</td>
<td>Est. (t-test)</td>
<td>Est. (t-test)</td>
</tr>
<tr>
<td><strong>Household characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly household income [1000 CHF]</td>
<td>0.0814 (12.42)</td>
<td>0.168 (22.96)</td>
<td>0.205 (17.73)</td>
<td></td>
</tr>
<tr>
<td>Single person household</td>
<td>-0.228 (-4.72)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1+ child aged 0 to 10</td>
<td>0.204 (5.04)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Children aged 11 to 18</td>
<td>0.134 (4.37)</td>
<td>0.107 (3.39)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Persons above 65</td>
<td>0.512 (20.64)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Driving licenses</td>
<td>0.588 (11.23)</td>
<td>1.07 (15.15)</td>
<td>1.35 (12.46)</td>
<td></td>
</tr>
<tr>
<td><strong>Job &amp; population density</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density within 800 meters</td>
<td>-0.0339 (-6.04)</td>
<td>-0.109 (-9.58)</td>
<td>-0.127 (-3.39)</td>
<td></td>
</tr>
<tr>
<td>Employment density within 800 meters</td>
<td>-0.0669 (-12.55)</td>
<td>-0.111 (-9.47)</td>
<td>-0.203 (-4.04)</td>
<td></td>
</tr>
<tr>
<td><strong>Macro-accessibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln(Population based public transport accessibility)</td>
<td>-0.339 (-13.51)</td>
<td>-0.492 (-16.79)</td>
<td>-0.935 (-9.02)</td>
<td></td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diversity index</td>
<td>-0.415 (-4.16)</td>
<td>-0.66 (-3.92)</td>
<td>-0.8 (-1.74)</td>
<td></td>
</tr>
<tr>
<td><strong>Distances</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearest tram</td>
<td>-0.132 (-3.26)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Constants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>45,054</td>
<td>39,915</td>
<td>23,764</td>
<td>2,929</td>
</tr>
<tr>
<td>Chosen</td>
<td>9,075</td>
<td>23,886</td>
<td>11,187</td>
<td>906</td>
</tr>
<tr>
<td>Adjusted rho-square</td>
<td>0.32</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 6.7: Vehicle ownership and walk index for Singapore and Switzerland

and after-school activities are not omnipresent yet. Desired mobility might be achieved by public transport only. Having two young children however increases the utility of owning one vehicle. For two vehicles a similar preference structure holds: having one child does not increase the utility of two vehicles, having two young children still does not increase the utility of two vehicles. Households with one or more teenagers in the household have higher benefits from two vehicles. For households owning three vehicles no significant effect could be found in relation to the number of children.

Driving licenses have been included in the model estimations as the number of licenses within the household. An increasing number of driving licenses positively influences the propensity to own a vehicle.

Population density, and job density to a lesser extent, first and foremost represent urbanity. As the model is estimated for Switzerland as a whole, we explicitly choose to not include variables the distance to next centre or CBD. Parameter estimates for both population and employment density are negative and of increasing (negative) influence as the choice for the number
of vehicles increase. While the influence on one vehicle is minor, for two and three vehicles the influence is larger. It is hypothesized that this is due to more activities being in reach by foot or public transport on one hand, and on other hand that the parking might not be available in areas with a high population and/or employment density.

Different specifications of macro-accessibility have been entered into the utility function of the model, including differences between and ratios of private and public transport accessibility. Taking the natural logarithm of a place-based public transport accessibility measure (chapter 3) yielded the best model result; it should be mentioned that a similar transformation of the accessibility to jobs with the same distance decay factor yielded a model with slightly lower log-likelihood. A high public transport accessibility decreases the probability of owning more vehicles.

Including both a walk index and a diversity index yielded insignificant parameter estimates due to colinearity. A higher diversity lowers the likelihood of owning one or more vehicles, the effect being stronger for the choice for two or more vehicles. A wide range of specifications of the destination index was included in intermediary models, including interaction terms, transformations, quartiles and percentiles. In all cases, models with the diversity index outperformed models with a destination index or a combinations of the diversity and density index. Including a diversity index that considered a cumulative Gaussian distance decay function performed best, as opposed to mode choice models, where the diversity within 300 meters network distance yielded significant results (see chapter 5).

Network distances to bus stops, tram stops, train stations, primary schools and secondary schools have been included in intermediary model estimations. Only households owning one vehicle reveal a lower likelihood of owning one vehicle when a tram stop is present within 400 meters. Trams are only available in larger cities in Switzerland; a tram thus does not only give an indication of the public transport system, but also of the urban environment surrounding the household. In addition to the public transport convenience and additional amenities it might also represent a potential lack of parking space for a second vehicle.

\textit{MNL results: Singapore}

Table 6.2 shows the model predicting functional vehicle ownership for households in Singapore. Again, all estimates are versus the alternative of
owning no vehicle. The variables mostly carry the expected sign and are statistically significant.

Income has been entered as income quintiles instead of a single continuous variable; it is expected that due to the high cost of vehicle ownership lower income groups will have a lower probability of owning a vehicle. Households in a higher income quintile have a higher probability of owning one or more vehicles; a tipping point can be observed at the third quintile, which equates to a monthly household income between SGD 3,000 and SGD 5,750.

Variables representing household structure reveal different preference structures for each alternative. Having children increases the propensity to own a vehicle; a differentiation between young and old children yielded insignificant estimates. Older households tend not to own a vehicle. Households with a Chinese background have a higher probability of owning a vehicle.

Households residing in HDB have a lower propensity of owning a vehicle; households residing in landed property have a higher probability of owning one vehicle. This effect is even stronger for owning two vehicles.

Similar to Switzerland it is found that an increase in driving licenses within the household increase the propensity to own a vehicle.

Different specifications of macro-accessibility have been entered into the utility function of the model, including differences between and ratios of private and public transport accessibility. Using a cumulative opportunities accessibility measure, instead of decay-based accessibility measure, yielded the best model result. A high public transport accessibility decreases the probability of owning more vehicles.

Again, including both a destination accessibility index and a diversity index yielded insignificant parameter estimates due to colinearity. A higher diversity lowers the likelihood of owning one vehicle. Also, diverse land-use mix variables were included; these were not significant. Eventually, it was the diversity index which describes the diversity was included by means of cumulative Gaussian distance decay function.

Network distances to bus stops, MRT stations, primary schools and secondary schools have been included in intermediary model estimations. These were excluded from the model specification as they were not significant.
### Table 6.2: Singapore: vehicle ownership model

<table>
<thead>
<tr>
<th></th>
<th>0 vehicles</th>
<th>1 vehicle</th>
<th>2 vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Est. (t-test)</td>
<td>Est. (t-test)</td>
<td>Est. (t-test)</td>
</tr>
<tr>
<td><strong>Household characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly household income [Quintile 1]</td>
<td>-0.688 (-6.81)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Monthly household income [Quintile 2]</td>
<td>-0.629 (-7.03)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Monthly household income [Quintile 3]</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Monthly household income [Quintile 4]</td>
<td>0.446 (5.9)</td>
<td>1.36 (6.01)</td>
<td>-</td>
</tr>
<tr>
<td>Monthly household income [Quintile 5]</td>
<td>0.602 (7.58)</td>
<td>2.2 (11.23)</td>
<td>-</td>
</tr>
<tr>
<td>Children aged 0 to 10</td>
<td>0.354 (4.65)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Children aged 10 to 18</td>
<td>0.339 (0.057)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Number of licenses</td>
<td>0.523 (10.92)</td>
<td>0.95 (10.61)</td>
<td>-</td>
</tr>
<tr>
<td>Chinese ethnicity</td>
<td>0.608 (8.9)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Dwelling characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDB</td>
<td>-1.15 (-9.67)</td>
<td>-1.44 (-8.18)</td>
<td>-</td>
</tr>
<tr>
<td>Condominium (reference)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Landed property</td>
<td>2.35 (10.24)</td>
<td>3.97 (16.41)</td>
<td>-</td>
</tr>
<tr>
<td><strong>Accessibility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>log (Public transport accessibility to jobs, cumulative 40 minutes)</td>
<td>-0.0394 (-3.2)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diversity</td>
<td>-0.342 (-2.11)</td>
<td>-1.21 (-3.94)</td>
<td>-</td>
</tr>
<tr>
<td><strong>Constants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>-2.72 (5.68)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Chosen</strong></td>
<td>6203</td>
<td>3025</td>
<td>406</td>
</tr>
<tr>
<td><strong>Adjusted rho-square</strong></td>
<td>0.206</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
6.4.2 Vehicle usage in Switzerland

**OLS Model specification**

To assess the influence of household characteristics, built environment and accessibility on a household’s vehicle kilometres traveled (VKT), an ordinary least squares (OLS) model was estimated. The Mikrozensus 2010 contains several questions concerning vehicle kilometres driven per vehicle in the household. As a dependent variable we take the log of the total yearly kilometres driven by a household minus the total kilometres driven outside of Switzerland. The latter are likely not to be the direct result of the built environment.

**OLS results**

In Table 6.3 the results are presented of the vehicle usage model. The number of vehicles owned the household increases the number of kilometres driven, as does the monthly household income. The number of children in a household increases VKT; an increase of persons aged 65 or over decreases VKT driven. The number of licenses in excess of the number of vehicles (marginal licenses) increases VKT driven as expected. A higher public transport accessibility yields a lower VKT. Population density, and to a lesser extent job density, decrease VKT. A higher destination diversity decreases VKT. Other densities, such as the number of bus and tram stops within 400 meters, decrease VKT. The number of intersections within 400 meter of the household decreases VKT. A wide range of distances to amenities was included in intermediate models. Only network distance to nearest supermarket yielded a significant estimate. Distances to transit and schools were insignificant, as were the estimates for the micro-accessibility to different types of opportunities.

6.4.3 Elasticities

To understand the relationships across the models, Table 6.4 provides the elasticities of the vehicle ownership for Switzerland Singapore, and usage model for Switzerland. Elasticity values for public transport for Switzerland indicate that public transport accessibility has substantial impact on the choice to own one or more vehicles. Once a household owns a vehicle, it is less sensitive to public transport accessibility. Diversity has a moderate influence on the choice to own one vehicle in Switzerland, and a substantial negative impact on the choice to own two or more vehicles. Population
density has a weak, negative, relationship with vehicle ownership. However, the relationship is stronger for household owning two or more vehicles. Households living in more densely populated areas generate less VKT. A similar preference structure for vehicle ownership is revealed with regard to employment density. By contrast, a higher employment density will not lead to a decrease in VKT. For Singapore, the elasticity value of public transport indicates a negative, but marginal effect on the choice to one vehicle. Diversity on the other hand, has a moderate impact on the choice to own two vehicles.
Table 6.4: Direct aggregate elasticity effects for vehicle ownership and usage

<table>
<thead>
<tr>
<th>Variable</th>
<th>One vehicle</th>
<th>Two vehicles</th>
<th>Three vehicles</th>
<th>Vehicle usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income (1000 CHF)</td>
<td>0.19</td>
<td>0.70</td>
<td>1.37</td>
<td>0.26</td>
</tr>
<tr>
<td>Population density within 800 meters</td>
<td>-0.04</td>
<td>-0.24</td>
<td>-0.16</td>
<td>-0.10</td>
</tr>
<tr>
<td>Employment density within 800 meters</td>
<td>-0.05</td>
<td>-0.16</td>
<td>-0.12</td>
<td>-0.01</td>
</tr>
<tr>
<td>Diversity</td>
<td>-0.21</td>
<td>-0.61</td>
<td>-1.05</td>
<td>-0.02</td>
</tr>
<tr>
<td>ln (Public transport accessibility)</td>
<td>-1.13</td>
<td>-2.46</td>
<td>-3.26</td>
<td>-0.03</td>
</tr>
<tr>
<td>Singapore</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diversity</td>
<td>-0.14</td>
<td>-0.76</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ln (Public transport accessibility)</td>
<td>-0.06</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

6.5 Conclusion

This chapter has set out to investigate the role of built environment and accessibility on vehicle ownership and usage for the entire Switzerland and vehicle ownership for Singapore. After controlling for household income, license ownership and household composition, built environment and accessibility significantly influence vehicle ownership and usage.

For both countries, households with one young child have a lower likelihood of owning one vehicle or purchasing a second vehicle than households with two or more young children or teenagers. As models were estimated on a cross-sectional data set variables describing household structure cannot be interpreted as key turning points in life to own a vehicle. Based on retrospective mobility biographies Beige and Axhausen (2012) they find that an increase of household size is a turning point leading to vehicle ownership.

For the computation of micro-accessibility Google Places has been used as a main data source; distances to these opportunities has been calculated and inserted into an accessibility computation. Two indexes have been constructed based on this data: a diversity index and a destination
index. A higher diversity of destinations within walking distance decreases the likelihood of owning one or more vehicles. A combination of a diversity index and destination index led to insignificant parameter estimates, indicating the overlap between these variables.

Both Singaporean and Swiss households living in an area with high public transport accessibility are less likely to own a vehicle. Once a household owns a vehicle kilometres drives however, it is less sensitive to public transport accessibility.

The models for vehicle ownership and usage have several overlapping parameters. Most interesting however are the differences between the models: children within a household play a large role in ownership decision but do not result in a higher usage as compared to households without children. The number of persons aged 65 and over increases the probability of owning a vehicle but decreases usage. Ownership is negatively influenced by the proximity of a tram; usage decreases if a supermarket is present within 500 meters of the dwelling. Distances to other opportunities were not significant in either model.

Further efforts will be made to combine the number of destinations, a destination weight and destination diversity into the utility function or into a single function.

In the models public transport usage was not estimated. While diversity and density decrease vehicle ownership, they might not decrease motorized transport and increase the usage of active modes. Current trends in Switzerland indicate an increase in long distance public transport commuting, this being ever more attractive due to decreasing travel times and low marginal cost through season tickets.

Also, the interaction between density and diversity was not investigated. Does a dense and diverse neighborhood lower vehicle ownership levels even further? Also, how does parking relate to density and diversity? Dense neighbourhoods might have less parking available, as do diverse neighbourhoods.

The most important contribution to daily vehicle kilometres travelled stems from leisure trips. Both the vehicle ownership and vehicle usage model do not include a variable specifying accessibility to leisure opportunities, except for parks being included in the diversity index. More research is necessary to define leisure locations, collect relevant data and enter this into the vehicle usage model.
Finally: between macro-accessibility and micro-accessibility is meso-accessibility. We envisage this a more personalized accessibility index, based on amenities beyond walking distance, and known to the decision-maker. Examples of these amenities can include opportunities such as employment location, preferred shopping and entertainment areas and opportunities to interact with friends and family. Meso-accessibility might influence ownership and most certainly usage more than micro and macro-accessibility.
Chapter 7

Residential mobility & location choice

This chapter is based on van Eggermond et al. (2012) and Schirmer et al. (2014)

7.1 Introduction

Residential mobility and location choice is one of the driving forces of urban dynamics. The outcomes of household’s choices impact social structure, spatial segregation, transportation flows, the supply of labor and the demand for amenities such as housing, education, shopping and recreation (Mulder and Hooimeijer, 1999).

Rossi (1955) shifted the focus of research to the individual household and its motivation to look for another dwelling, as opposed to the study of aggregate patterns of mobility and origin-destination patterns (Dieleman, 2001). While the focal point of analysis has shifted towards the household, the majority of the studies over the last decades still has focused on the choice of residential location between administrative zones as opposed to the residential unit households actually choose.

The eventual choice for a residential unit is the result of an elaborate decision process. Brown and Moore (1970) divide this process in two phases: (1) the decision to seek a new residence and (2) the relocation decision, comprising of both search and evaluation. A conceptualization of the decision to move is provided by the three-stage approach housing opportunities (Phipps and Laverty, 1983). These three stages are: (1) the decision to move, (2) the search for a suitable dwelling and (3) the final
Chapter 7. Residential mobility & location choice

choice whether to move or not to move into the chosen dwelling (i.e. Mulder, 1996).

The characterization of residential mobility and location choice lends itself to be described by discrete choice models: the choice whether to move, and the residential areas and dwelling units are clearly demarcated alternatives. The discrete choice modelling approach was introduced to residential location choice by McFadden (1978). Since then, it has found wide acceptance amongst transportation researchers. Initial studies considered households which move to a certain zone (Weisbrod et al., 1980; Anas, 1982). Each zone was attributed characteristics, such as housing price, employment level, crime rate and accessibility to other zones or employment; a choice is made between all zones based on the zonal attributes and the socio-economic characteristics of the household. More recent studies (Habib and Miller, 2009; Lee et al., 2010) have shown that considering the residential unit as choice alternative, instead of the zone, and including building specific attributes, explains the residential location choice of households better.

Discrete choice models were developed for an aspatial environment and the complexity of space is not always accounted for (Pellegrini and Fotheringham, 2002). Several characteristics of the discrete choice models should be closely minded in a spatial context (Guo, 2004): (1) the definition of the alternatives, (2) the definition of the choice set, (3) the substitutability amongst alternatives and (4) the measurement of spatial variables.

Previous literature reviews have, amongst others, considered spatial choice set formation (Thill, 1992; Pagliara and Timmermans, 2009) and the modelling of spatial choice (Pellegrini and Fotheringham, 2002). This chapter contributes to these previous studies by specifically addressing the issues put forward in these papers and combining them with a wide range of studies concerning residential location choice.

This chapter continues with a literature review of residential mobility search and location choice in section 7.2; Section 7.3 continues with an overview of choice set formation and generation.
7.2 Residential mobility

Residential mobility is the primary means of making an adjustment in housing consumption and largely is the result of housing dissatisfaction (Rossi, 1955). Prior to making the adjustment in the housing consumption, households develop the desire to move.

There are several mechanisms keeping people where they are and pose constraints, or even limit the desire to move (Mulder, 1996), in addition to triggers that can result in a move.

Mulder (1996) outlines three mechanisms that prevent persons and households from moving: (1) The transaction costs associated with the search for a dwelling, and subsequently the move itself, is considered too high of a burden to proceed with the move, (2) The location-specific capital is considered too valuable to move away from. This capital can stem from the dwelling itself (purchase costs, home improvements) or the location of the dwelling within the daily activity space, especially in the presence of children or a second earner within the household and (3) in western societies, the place of residence is a source of identity.

The onset of the search process is caused by one or more moving triggers; a situation occurs where the current housing does not match a households goals. Rossi (1955) hypothesizes that changes in household life cycle result in residential mobility. Additionally, residential mobility can result from changes in the social and physical amenities offered by the residential location, or a change in the standard to evaluate these factors (Quigley and Weinberg, 1977).

Dieleman (2001) highlights three regularities in residential mobility which are prevalent in the Western world (i.e. United States and Northwest Europe): (1) the correlation between the rate of mobility and the life cycle of a person; young adults between 20 and 35 are the most mobile segments of the population, (2) the correlation between the rate of mobility and the size and tenure of the current dwelling. Households in large dwellings are less mobile as compared to households in smaller dwellings. Owner-occupiers have a lower mobility rate than renters, (3) there are clear relationships between the housing career of a person and life course events in the realm of family, education and professional career.

Clark and Onaka (1983) further formalize reasons for moving: (1) a voluntary move resulting from changes in the housing market and institutional
structure: (2) a voluntary move resulting from changes in household life cycle and (3) forced moves resulting from a loss of the current housing unit. Moves motivated by these factors are also called 'adjustment', 'induced' and 'forced' moves. Adjustment moves encompass three categories of reasons for moving: housing unit characteristics (including tenure), neighbourhood characteristics and accessibility. Induced moves encompass two categories of reasons for moving: employment changes (including education changes) and life cycle changes. In a study for both the entire United Kingdom and London Clark and Huang (2003) find that moves can be explained by room stress, defined as the mismatch between actual number of rooms and required number (adjustment reasons), house ownership (owners tend not to move) and life cycle (induced reasons).

7.3 Search process

7.3.1 Choice set formation & generation

The goal of residential location choice modelling is to predict the probability a decision-maker to choose a certain alternative on one hand and to determine the relative weight of attributes within the alternative on the other hand. Following from this notion stems first the necessity to define the alternative and second to define the set of alternatives. In the previous section the notion of the alternative has been addressed. The set of alternatives follows from the level of granularity appropriate for the choice context.

Two streams of research can be recognized in this context: choice set formation and choice set generation. Whereas choice set formation is a behavioural process executed by the decision-maker, choice set generation is usually referred to as the process carried out by the analyst either to mimic the choice set formation process or to limit the number of alternatives for computational purposes and tractable model estimates.

Within the two-stage choice decision process, the eventual residential choice is made from a set of alternatives, or the choice set. The set of all possible alternatives is commonly dubbed the universal choice set. A recurring question is which alternatives are considered immediately prior to the choice and how these alternatives were selected from the universal choice set.
Shocker et al. (1991) make a distinction between the awareness set, the consideration set and the choice set. The awareness set consists of the alternatives choice set of which the decision-maker is aware. The consideration set contains alternatives that meet the decision-makers criteria. The choice set contains the alternatives considered immediately prior to the decision. Either way, several different choice set notions exist; varying in name, but similar in definition. Bovy and Stern (1990) highlights the following sets of alternatives: (1) existing opportunities (or the universal choice set): these include all possible alternatives, in the case of route choice between an origin and destination, but in the case of residential location choice the alternatives available to the decision-maker between the moment he enters the market, until he leaves the market, including alternatives under construction, (2) known alternatives: which are a subset of the existing alternatives known to the decision-maker, (3) available alternatives: which constitute a subset of the known alternatives that can potentially satisfy the decision-maker’s needs, and meets the decision-maker’s constraints, (4) feasible alternatives: being a subset of the competing available alternatives between which the traveller has to make a trade-off (5) used alternatives: which are the alternatives actually chosen.

Ortúzar and Willumsen (2011, p. 271) state three approaches to choice set generation: (1) the use of heuristics or deterministic choice-set generation rules which permit the exclusion of certain alternatives, (2) the collection of choice-set information directly from surveys, simply by asking respondents about their perception of available options, (3) the use of random choice sets, whereby choice probabilities are considered to be the result of a two-stage process: first, a choice-set generating process, in which the probability distribution function over all possible choice sets is determined; and secondly, conditional on a specific choice set, a probability of choice for each alternative is determined (Richardson, 1982; Lerman, 1984).

### 7.3.2 Choice set formation & generation in a housing context

Most spatial choices are made from a large pool of potential alternatives; residential location choice is no exception to this rule. The manner in which residential alternatives are considered and assumed to be processed by an individual, depends on the researchers’ assumptions regarding the
underlying decision process.

In a housing context, the total number of housing opportunities available to the households can be denoted as the vacancy set (Mulder, 1996). On one hand, the consideration set, is limited due to housing policies, price, number of rooms and other criteria is denoted as the possibility set. On the other hand, the consideration set is formed by the households awareness space: the locations within the total urban space of which the potential mover has knowledge (Brown and Moore, 1970). This information is obtained through the daily activity space of the household, and information derived through secondary channels, such as newspapers, advertisements, social media and the social network.

Within the three-stage choice decision process different parameters are of relevance for the search stage: the search of housing is performed within a certain search space and with a certain search intensity (Mulder, 1996). The search space can be operationalized in several ways. A starting point for the spatial extent of the search space can be found in the bid-rent concept, originating in Von Thünen’s work (von Thünen, 1966) on agricultural land use and later applied by Alonso (1964) to residential location. Here it is assumed that each individual has a bid-curve. The residential bid price curve is the set of prices for land the individual could pay at various locations while deriving a constant level of satisfaction. Market prices are determined by the equilibrium condition; no household should be better off by changing its location. Alonso assumes a mono-centric city: all employment is located in the city centre and location is a function of transportation and housing costs. The search space can then be seen as radiating outwards from the city centre.

Barrett (1976) measures search behaviour and shows households examine a few properties within a limited spatial extent of search. A clear search space is not found; however the extent differs for intra-urban movers and peripheral movers. It is hypothesized that this difference is due to residential supply; more vacancies would be available in the periphery and movers needed to perform more effort for these properties. Therefore, they would aim to schedule visits to multiple properties while in the area.

Huff (1986) introduces the constrained choice set model, in which households are limited to certain areas due to vacancies meeting their criteria. This model is further refined with the area based search model and an anchor based search model. In the area-based model, households first
select an area and subsequently search for vacancies. In the anchor-based model, vacancies surrounding one or more anchor points (for instance, a households work and education locations) are included in the search process.

It is possible that these anchor points are not specific to households activity space but specific to urban form. Moving away from a monocentric city with a single employment centre, it is possible that a household search space includes the city centre, but as no suitable vacancies found, subcentres are preferred above locations close to the city centre (e.g. Thierstein et al., 2013). These subcentres are preferred as they contain similar amenities as the main centre and provide good access to the centre.

If the alternative is considered to be the individual residential unit, it becomes necessary to review the choice set formation and generations aspects of residential location models. By considering the residential unit as alternative, the number of alternatives available to the decision-maker will increase strongly and limiting the choice set becomes necessary to obtain behavioural and computational tractable model estimates. Wrongly specifying the choice set can lead to incorrect model estimates or wrongly predicted market shares (Pagliara and Timmermans, 2009).

Choice set generation is commonly applied in residential location choice studies to decrease the number of alternatives. Most studies either consider the universal choice set of the decision-maker or sample from the universal choice set (Eliasson, 2010; Lee and Waddell, 2010; Lee et al., 2010; Habib and Miller, 2009; Chen et al., 2008; Palma et al., 2007; Guo and Bhat, 2002). Cascetta et al. (2011) propose a methodology to identify dominance attributes which may be defined in different ways, possibly in accordance with the specific choice context, and which way they can be introduced as perception attributes in random utility models. They apply it to residential location choice by defining specific dominance attributes. Their estimation results show a generally high significance of all these attributes and a considerable improvement in the model’s goodness-of-fit statistics. The use of dominance variables has been also tested as a sampling technique. Their results show that the weighted sampling gives parameters’ estimates ’closer’ to those obtained with full choice set.

Rashidi and Mohammadian (2010) and Zolfaghari et al. (2012) apply a hazard based choice set formation model and set thresholds on acceptable property price and commuting times. They find that random sampling
outperforms both the models with a universal choice set and a generated choice set with thresholds on commuting time; choice set formation did not sufficiently capture housing cost and commute time.

7.3.3 Aspects of markets and policy in choice set formation

Whereas in the framework sketched, considering route choice, the universal set of routes is clearly given by the network, the set of residential alternatives available to a decision-maker cannot be separated from the workings of the real estate market. Within a zonal context, it is not necessary to consider this as it might be assumed that a dwelling is available within a zone. The ensuing discussion is by no means exhaustive, but intends to present aspects of residential markets possibly influencing choice set formation.

Equilibrium in housing markets

A first aspect relates to the supply of dwelling units versus the demand. This aspect relates to the liquidity in the real estate market: the number of units coming available in a certain time period and the time that these units are available. In line with micro-economic theory it can be expected that in a market with low liquidity and high demand, demand will outrun supply on the short term. A potential seller or landlord might either select a buyer based on the bid or the bidders’ credentials. A special case of the latter is the situation where current residents have to approve the new resident. Examples can be found in the cooperation (Genossenschaft) market in Switzerland and the upmarket condominiums in New York.

In an equilibrium condition, i.e. housing supply meets housing demand, each of the alternatives will be chosen by some household and prices will clear the market. It can however occur that housing supply is limited and that this is not fully accounted for by prices; a realistic assumption in the short-term, where disequilibrium is common. The interaction between seller and buyer is neglected in choice models, leading to price endogeneity. Martínez (1992, 1996) reconciles the bid-rent approach with the discrete choice framework and introduces the bid-choice model to incorporate this interaction. Hurtubia and Bierlaire (2011) develop a microsimulation based on the bid-choice model in which demand and supply surplus can be simulated. On the other hand, Guevara (2010) states that in the case of residential location choice, if the demand and supply are treated at a
microscopic scale, this source of endogeneity might not be significant because the price of each dwelling is not likely to be determined by the choice made by any particular household. Moreover, the effect of all agents on dwelling price would become apparent only in the medium term, mitigating any potential endogeneity effect from this source in residential location choice models.

Public and private housing
A second aspect within the residential market is the division between private housing and public housing, where the latter type of housing can be provided by the state or local governments. On one hand, public housing may be constrained to certain groups within a society, thus influencing the availability of these residential alternatives. On other hand, the allocation mechanisms within the private and public housing market can influence the choice set formation process. Examples of such allocation mechanisms can be found in waiting lists based on a first come first served queue, common for instance within the public housing market in the Netherlands (van de Veer and Schuiling, 2005) or a balloting system, as is the case in Singapore (e.g. Phang, 2007). In the latter case households choose to ballot for certain housing projects and are considered eligible if they meet criteria concerning income, age and household composition.

Tenure
A final aspect to be addressed in this section concerns differences between home ownership and tenants, which translates into home ownership versus tenancy. For tenants, on one hand, this translates into the security and type of tenure within the current residence. Households with a fixed term contract can expected to have a higher urgency to search for a new dwelling near contract expiration date than home owners do or tenants well protected by laws. It can be expected that households with a high urgency to find a new dwelling might make different trade-offs when choosing and searching for residential alternatives. These households may follow different decision-rules, such as satisficing (Simon, 1958) or regret minimization (Chorus et al., 2008) and utility maximisation may not be the decision-rule followed. For home owners searching a new residence might have less urgency and a longer search process might be considered. Also, in addition to the trade-off between different attributes their decision can be additionally based on market expectations, i.e. will prices drop or rise in a certain area.
7.4 Evaluation and choice

Once a decision to move is made and one or more vacancies are considered to be relevant residential alternatives, the individuals or households requirements must be explicit to evaluate the alternative(s); prior to the decision requirements can be seen as implicit (Brown and Moore, 1970). Tversky (1972) discusses the heuristic elimination by aspects; the most important attribute is determined and a cut-off value is retrieved by the decision-maker. All alternatives with a value below that cut-off are eliminated. Prospect theory (Kahneman and Tversky, 1979) describes the decision-making process in two stages. In the first stage alternatives are framed: a reference point is set against which alternatives are evaluated. In the second stage alternatives are evaluated against this reference point in terms of gains and losses. Studies by Chen et al. (2008) and Habib and Miller (2009) apply concepts of prospect theory and provide evidence that the previous location and accessibility to different types of amenities play a role in choosing a new location.

Traditionally, residential location choice studies have considered the zone as level of analysis (e.g. Zolfaghari et al., 2012; Chen et al., 2008; Weisbrod et al., 1980). More recently, a series of studies has analysed the neighbourhood (Guo and Bhat, 2007), the parcel (Srour et al., 2002), the building (Lee et al., 2010; Lee and Waddell, 2010) or the dwelling unit (Habib and Miller, 2009; Belart, 2011; Schirmer et al., 2013).

Considering the residential unit or building as alternatives offers the possibility to include the units’ and buildings’ characteristics and, according to the cited studies, improves model performance. Furthermore this offers the opportunity to include a detailed description of the buildings’ built environment and the calculation of detailed travel times and accessibility measures.

A review on the role of location in residential location was conducted by Schirmer et al. (2014). The authors categorized locational variables in residential location models in the following categories: (1) built environment, including buildings, parcels, blocks and connecting networks, (2) socio-economic environment, an umbrella term, characterized by variables describing various aspects of society: population size, income level, ethnic distribution, age and education level, (3) points of interest; points of interest provide functions relevant to the public, and (4) accessibility, which is the
product of interest points and the transport network. The findings of their literature review are reported in Table 7.1 and Table 7.2.

Households prefer different types of land-use mixes in different life cycle stages. Attributes describing the socio-economic environment are still important in residential location choice models. Household clustering can be observed in a wide range of studies, with households preferring to live near other households with a similar composition or income. Single households and young persons gravitate toward population-dense areas.

Education, service, retail, and local transport facilities are valued by all household types; both proximity to and the density of these amenities is appreciated. Preferences for stations and highway ramps vary, depending on household car availability and the noise level caused by these transportation facilities. Young households tend to favour proximity to the central business district, while other household types would rather locate away from the urban core.

Longer commuting distances are perceived as negative. Preferences for accessibility to employment differs: the authors hypothesize that this can be due to different calculation methods and accessibility indices. Households search for a job close to their residence or, when relocating, take into account the location of their current job and consider accessibility to jobs less important. Accessibility to shopping opportunities is considered positive by households.

7.5 Conclusion

This chapter discussed the literature on residential mobility and location choice. Residential mobility is either characterized as two-stage approach, where the decision to move is followed by the choice from a set of residential alternatives, or as a three-stage approach, where the decision to move is followed by search; once a suitable alternative is found this alternative if evaluated against the initial decision to move.

Households and persons may move, or have to move because of reasons that fall into three categories: (1) induced moves, (2) adjustment moves, and (3) forced moves. Induced moves includes moves because of changes in household, employment and/or education reasons. The far majority of moves occur because of changes in household composition and life cycle
### Table 7.1: Main findings in reviewed studies by Schirmer et al. (2014)

<table>
<thead>
<tr>
<th>Group / Subgroup</th>
<th>Variable</th>
<th>Function</th>
<th>Radius</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Residential unit</strong></td>
<td>size: floorspace per person * (non single hh &amp; single hh)</td>
<td>value</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>rooms per person * non single hh</td>
<td>value</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>room per person * single hh</td>
<td>value</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>costs: (price/income) * hh is owner</td>
<td>value</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(price/income) * hh is renter</td>
<td>value</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>house type: detached single family * hh with children</td>
<td>value</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>multifamily housing * single person hh</td>
<td>value</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>age: building age</td>
<td>value</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Built environment</strong></td>
<td>built density: log (density of dwelling units in 600m)</td>
<td>density</td>
<td>500</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>log(density of dwelling units) * hh has children</td>
<td>density</td>
<td>500</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>log(density of dwelling units) * (young hh or single hh)</td>
<td>density</td>
<td>500</td>
<td>+</td>
</tr>
<tr>
<td>open space: share of open space or unbuilt space</td>
<td>ratio</td>
<td>500</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>share of water</td>
<td>ratio</td>
<td>500</td>
<td>+</td>
</tr>
<tr>
<td>land use: share of commercial land use * (young hh or single hh)</td>
<td>ratio</td>
<td>500</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>share of commercial land use * hh has children</td>
<td>ratio</td>
<td>500</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>share of industrial land</td>
<td>ratio</td>
<td>500</td>
<td>-</td>
</tr>
<tr>
<td>network/noise: buffer to arterials and railways (noise)</td>
<td>boolean</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>structural density (amount of network links per sqkm)</td>
<td></td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td><strong>Socio-economic environment</strong></td>
<td>population density: population density</td>
<td>density</td>
<td>1000</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>populations density * (young hh or single hh)</td>
<td>density</td>
<td>1000</td>
<td>+</td>
</tr>
<tr>
<td>household type: share of hh with same size</td>
<td>ratio</td>
<td>1000</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>share of hh with same age</td>
<td>ratio</td>
<td>1000</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>share of hh with children * hh has children</td>
<td>ratio</td>
<td>1000</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>share of hh with same income cat</td>
<td>ratio</td>
<td>1000</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>share of hh of same ethnic group/origin</td>
<td>ratio</td>
<td>1000</td>
<td>+</td>
</tr>
<tr>
<td>employment: unemployment rate</td>
<td>value</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>crime: crime rate</td>
<td>value</td>
<td></td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
Table 7.2: Main findings in reviewed studies by Schirmer et al. (2014), continued

<table>
<thead>
<tr>
<th>Group / Subgroup</th>
<th>Variable</th>
<th>Function</th>
<th>Radius</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Points of interest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>education</td>
<td>distance to school</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>urban character</td>
<td>distance to urban center (CBD) *</td>
<td>distance</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(nonsingle hh or hh has children)</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>distance to urban center (CBD) * (young hh or single hh)</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>distance to local center</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>service and retail</td>
<td>density of retail</td>
<td>density</td>
<td>500</td>
<td>+</td>
</tr>
<tr>
<td>sport and recreation</td>
<td>density of service</td>
<td>density</td>
<td>500</td>
<td>+</td>
</tr>
<tr>
<td>transport</td>
<td>density of sport activity centers</td>
<td>density</td>
<td>500</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>density of natural recreation centers</td>
<td>density</td>
<td>500</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>distance to local transport</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>distance to station * no car owner</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very close proximity to station (noisy environmnet)</td>
<td>value</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>distance to highway exit * car owner</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Access &amp; Accessibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>commuting time</td>
<td>commuting time/distance/costs by car *</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>car available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>commuting time/distance/costs by pt * no car available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sociodemographic accessibility (cumulative opportunities) of jobs * (no car or young or single)</td>
<td>acc</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POIs</td>
<td>accessibility (cumulative opportunities) of shops</td>
<td>acc</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><strong>Previous location &amp; Social networks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>individual distances</td>
<td>distance to previous location</td>
<td>distance</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>distance to social network</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
changes. Adjustment moves can occur because of the willingness to adjust housing consumption: a household can have too little or too much space. Another type of adjustment can be found in the tenure type. Home owners are less likely to move than tenants. Forced moves can for instance occur when people are evicted from their dwelling.

When the residential alternative is considered to be the residential unit, it becomes necessary to review the choice set formation and generation aspects of residential location models: the number of alternatives available to the decision-maker will increase strongly. Several possibilities exist to limit the number of alternatives. First, findings in literature suggest to introduce locational constraints on the search process, either by introducing anchor points or by limiting the search space to a restricted area. Second, households will only be active on the market for a short span of time. Third, affordability constraints are the results of the household’s financial means; on other hand, household composition will lead to requirements on the dwellings in the choice set.

Also, residential alternatives will become more similar and substitutable due to the limits on the search if the residential unit is considered to be the alternative. Alternatives differ based on their price, availability and their spatial attributes on a micro-level. Traditional spatial attributes such as zonal accessibility and density should be reviewed.

The next chapter looks into development of a residential mobility and location choice survey for Singapore. Chapter 9 continues with an analysis of residential mobility; Chapter 10 looks into choice set formation and generation for Singapore.
Chapter 8

Residential survey for Singapore

8.1 Introduction

This chapter addresses the development, content and execution of a survey investigating residential mobility and location choice in Singapore. Residential mobility and location are key components in land-use and transport demand models; the most frequent trips in Singapore are between the home and work location. For the further development of the MATSim for Singapore (Erath et al., 2012) there was a need for an insight into residential mobility and location choice. Given that the Singapore-MIT Alliance for Research and Technology was faced with a similar challenge it was decided to develop a residential mobility and location choice survey in collaboration with each other.

Given the lack of (publicly) available data sources on these topics a survey was developed to obtain insight in moving triggers and location in Singapore. The survey consisted of two major parts: (1) an incidence survey targeted towards the general population, and (2) the main survey, targeted towards recent movers. In total, the survey results over 7,000 complete responses. Over 1,000 respondents stated to have moved house in the 3 years prior to the survey and participated in the second part of the survey.

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1 The survey was designed by the author, Jingsi Shaw (MIT), Joe Ferreira (MIT), Christopher P. Zegras (MIT), and Kay W. Axhausen (ETH Zurich) and administered by the market research company GfK. The analysis presented in this chapter and subsequent chapters is fully the work of the author.
Section 8.2 continues with the design of the survey. Section 8.3 presents more details on the execution of the survey. Section 8.4 assess the representativeness of the sample.

### 8.2 Survey design

#### 8.2.1 Incidence survey

The first survey aimed to gain insight into residential mobility of Singapore’s resident population in different life-cycle stages and between different ethnic groups.

First, a number of questions was included to assess the overall representativeness of the respondents. These questions included gender, ethnicity, personal income, household income, household size, year of birth, dwelling type, tenure, planning area and sub-zone.

Given the overwhelming evidence in the literature that moves are mainly triggered because of induced reasons (e.g. changes in life cycle, employment and education) and for adjustment reasons (e.g. larger or smaller dwelling), several questions were included on life cycle and household composition. The first series of questions concerned the respondents living arrangements, whether the respondent had a partner and the respondent was married. A more detailed set of questions aimed to determine the household structure by asking for the relationship of each person in the household and their year of birth. Combined with the questions concerning with whom the respondent is living, an assessment of the role of the respondent in the household is possible.

De Groot et al. (2011) investigate the intentions to move and actual behaviour in the Netherlands. In their study, a number of studies are cited that highlight the fact that between 40% and 80% of the households with the desire to move, the thought of moving, or have the expectation to move, do so within two years. To assess the intentions of respondents to move they were asked whether they had made an advance purchase for a dwelling with the intention of living there. This advance purchase can be considered as the strongest intention to move. If a respondent did not purchase a house with the intention of living there in the three years prior to the survey, the respondent was asked whether he or she had intentions to move, and if negative the reasons for not wanting to move house.
8.2.2 Main survey

Eligible respondents were routed to the second, longer, part without being aware of being selected to participate in the second part. This survey consisted of eight sections. First, respondents were asked for more detailed information on the current dwelling, the type of HDB purchase and whether they were eligible for any HDB priority programmes. Also, respondents were asked to state reasons for being attracted to their current dwelling (pull reasons).

Subsequently, respondents were faced with a series of questions concerning the search process for their current residence. Questions included the price range, the size range and the number of rooms respondents preferred. For each of the property market strata, they were asked whether they considered this strata, and in which areas they considered properties. Furthermore, the number of considered, seriously considered and visited properties was asked for. A dedicated set of questions concerned the most competitive dwelling to the selected dwelling in the search process.

For each of the household members the current primary activity was asked for, and in which year this primary activity commenced. If the activity commenced less than 3 years prior to the survey year, the one before last primary activity was asked for and in which planning area this activity took place.

The household is considered to be the decision-making unit in residential mobility (e.g. Rossi, 1955; Brown and Moore, 1970). However, especially in decisions surrounding the decision to move house the household might be an ill-defined concept. Members of a household may leave their current household and form a new household, either by living themselves, or by deciding to live together with a partner. To be able to capture this question questions were included who left and entered the household, as well as questions concerning the household composition.

The survey continued with a series of questions on the previous residence, such as size, location, tenure and type to be able the determine the differences between the current and previous dwelling. To complement these measurable changes in the household structure and location, a series of question concerned the reasons for moving house (push reasons). Following the Housing Demand Survey conducted in the Netherlands (CBS, 2012), push reasons were divided into life cycle related reasons, reasons other than life cycle, dwelling related reasons and reasons related to dwelling’s
environment.

The relevance of the social networks was shown by Vyvere et al. (1998) and Belart (2011); moving away from social contacts was perceived negative. To assess the preference for living close to parents and friends questions were included where respondent’s parents resided, where their five closest friends resided, and where they met these five friends for the last time.

The survey concluded with a number of questions concerning the location of discretionary activities, such as grocery shopping, leisure shopping and the location of other leisure activity locations.

### 8.2.3 Spatial knowledge & preferences

Both the incidence survey and the main survey contain a number of questions concerning the location of the current dwelling, the previous dwelling, primary and secondary activity locations, the location of the respondent’s parents and the location of the five closest social contacts. It is possible to ask questions regarding location on different levels of spatial resolution. Ideally, a respondent is asked to pinpoint a location on a map. However, pre-tests had shown that respondents had difficulties pinpointing an exact location without additional support from a supervisor and that pinpointing a location on a map, even with an auto-fill address bar would take respondents a considerable amount of time. Instead of addresses respondents were therefore asked to select one or more planning areas on a map, and subsequently select a sub-zone from a list. This hierarchical approach had the additional advantage that respondents could provide information on the level of aggregation with which they were comfortable and knowledgeable.

Questions concerning location are shown in Table 8.1; an assessment of the spatial knowledge underlying these questions is given in Appendix B.1. In this Appendix, the process to derive a reference point for the current and previous dwelling is described. Summarizing, 77% of the respondents in the main survey have a postal code within the planning area they state to live in; 65% of the respondents in the main survey report a postal code within their previous dwelling areas. In both cases, these percentages increases with 13% to 90% respectively 78%.
Table 8.1: Spatial questions in incidence and main survey

<table>
<thead>
<tr>
<th>Question</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Planning zone</td>
</tr>
<tr>
<td>Current residence respondent</td>
<td>x</td>
</tr>
<tr>
<td>Previous residence respondent</td>
<td>-</td>
</tr>
<tr>
<td>Current employment respondent</td>
<td>x</td>
</tr>
<tr>
<td>Previous employment respondent</td>
<td>-</td>
</tr>
<tr>
<td>Current employment household member i</td>
<td>-</td>
</tr>
<tr>
<td>Previous employment household member i</td>
<td>-</td>
</tr>
<tr>
<td>Current education household member I, if primary school</td>
<td>-</td>
</tr>
<tr>
<td>Previous education household member I, all education</td>
<td>-</td>
</tr>
<tr>
<td>Current residence parents respondent</td>
<td>-</td>
</tr>
<tr>
<td>Current residence social network contact 1-5, respondent</td>
<td>-</td>
</tr>
<tr>
<td>Last meeting place social network contact 1-5, respondent</td>
<td>-</td>
</tr>
<tr>
<td>Locations for groceries</td>
<td>-</td>
</tr>
<tr>
<td>Locations for leisure</td>
<td>-</td>
</tr>
<tr>
<td>Locations for shopping</td>
<td>-</td>
</tr>
</tbody>
</table>

* Available for incidence survey

8.2.4 Estimated survey burden & survey duration

During the design of the survey questionnaire an estimation was made of the survey burden. For the estimation inspiration was taken from several sources addressing the a-priori assessment of survey burden (Berry, 2009; Axhausen and Weis, 2013; Versta Research, 2016). The survey duration is estimated by assigning each question a number of points, where the number of points is dependent on the complexity of the question. Axhausen and Weis (2013) provide a detailed point scheme, where the number of points differs from 3 points for a closed yes/no question to 9 points for an open-answer question. The total number of points is subsequently divided by the number of points that can be answered per minute, which amounts to 16 (Axhausen and Weis, 2013).

In Table 8.2, the estimated survey duration is presented. The total
survey was estimated to take 38 minutes, of which the incidence survey would take almost 7 minutes. The estimated survey duration assumes a single household member; each additional household member will take an additional 3.5 minutes. Also, it assumes a single social contact. For each social contact, an additional 2 minutes were estimated. For example, a respondent with two additional household members and 5 social contacts would take an estimated 51 minutes to complete the survey.

Table 8.2: Estimated survey duration

<table>
<thead>
<tr>
<th>Survey section</th>
<th>Point</th>
<th>Time per section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidence survey</td>
<td>108</td>
<td>6.75</td>
</tr>
<tr>
<td>Current residence</td>
<td>69</td>
<td>4.31</td>
</tr>
<tr>
<td>Search process</td>
<td>97</td>
<td>6.06</td>
</tr>
<tr>
<td>Most competitive alternative</td>
<td>37</td>
<td>2.31</td>
</tr>
<tr>
<td>Previous residence</td>
<td>80</td>
<td>5.00</td>
</tr>
<tr>
<td>About the respondent</td>
<td>73</td>
<td>4.56</td>
</tr>
<tr>
<td>About the household member*</td>
<td>57</td>
<td>3.56</td>
</tr>
<tr>
<td>Social network†</td>
<td>39</td>
<td>2.44</td>
</tr>
<tr>
<td>Activities &amp; location</td>
<td>45</td>
<td>2.81</td>
</tr>
<tr>
<td>Total time</td>
<td>605</td>
<td>37.81</td>
</tr>
</tbody>
</table>

*The number of points is only for one household member.
†The number of points is only for one contact.

The median survey duration for the incidence survey was 6.9 minutes (25% percentile took 5.1 minutes, 75% took 11 minutes). The median survey duration for the incidence and the main survey was 45 minutes (25% percentile took 32 minutes, 75% took 87 minutes).

8.3 Survey administration & execution

8.3.1 Methodology

The survey has been administered as a computer-based web assisted survey in collaboration with the market research firm GfK. Respondents were screened in the first survey on the following criteria: (1) whether they moved house in the three years prior to the survey date and (2) whether they purchased a dwelling with the intention of living in two years prior to the survey date. Eligible respondents continued with a more elaborate survey.
8.3.2 Sample & recruitment

Respondents were recruited via an online respondent panel and sampled according to a general representation of Singapore in terms of age, gender and race. For this survey, only respondents aged 18 and above were included in the recruitment process. The internet panel mainly contains Singapore citizens and permanent residents. Respondents for this panel are recruited via different channels. Survey respondents obtain credits for answering surveys; these credits can be exchanged for vouchers and products several times per year.

The survey was soft launched on November 26, 2015. In this soft launch, respondents were directly recruited so that the incidence survey and the main survey both would be completed. By December 1st, 2016, 107 respondents had completed the survey. Table 8.3 lists the number of respondents by date; pre-list indicates that respondents were screened prior to taking the survey, direct indicates respondents entering the survey without pre-screening. Please note that the time intervals are not equal, as these are the figures as communicated by the survey company at the mentioned dates. On January 4 the target number of respondents was reached and no more respondents were invited to participate.

8.4 Sample representativeness

To assess the representativeness of the sample of respondents, a comparison of their demographic characteristics was made with publicy available sources. Table 8.4 and Table 8.5 show the key-demographics of the survey’s respondents and Singapore’s general household survey 2015 (SingStat, 2016). A further analysis of the respondents’ age and household income is given in Figure 8.1 and Figure 8.2 respectively. Additionally, the table provides a further breakdown for respondents who have participated in the incidence survey and the main survey.

As of 2015, Singapore’s population stood at 5.54 million (NPTD, 2015). Singapore citizens form the majority of the population: there are 3.38 million Singaporeans. In addition, there 0.53 million permanent residents and 1.6 million non-residents, consisting of individuals with work passes and foreign students. In Table 8.4, an exact breakdown is given; only the ratio of permanent residents to Singapore citizen is presented in the column.
Table 8.3: Survey execution: cumulative number of respondents

<table>
<thead>
<tr>
<th></th>
<th>4-Dec-15</th>
<th>10-Dec-15</th>
<th>15-Dec-15</th>
<th>17-Dec-15</th>
<th>24-Dec-15</th>
<th>30-Dec-15</th>
<th>4-Jan-16</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-list</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entered</td>
<td>409</td>
<td>409</td>
<td>409</td>
<td>409</td>
<td>409</td>
<td>409</td>
<td>409</td>
</tr>
<tr>
<td>Incidence survey</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
<td>179</td>
</tr>
<tr>
<td>Main survey</td>
<td>107</td>
<td>107</td>
<td>107</td>
<td>107</td>
<td>107</td>
<td>107</td>
<td>107</td>
</tr>
<tr>
<td>Uncompleted (Incidence &amp; Main survey)</td>
<td>123</td>
<td>123</td>
<td>123</td>
<td>123</td>
<td>123</td>
<td>123</td>
<td>123</td>
</tr>
<tr>
<td><strong>Direct</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entered</td>
<td>1111</td>
<td>2665</td>
<td>3679</td>
<td>5391</td>
<td>6707</td>
<td>8863</td>
<td>10401</td>
</tr>
<tr>
<td>Incidence survey</td>
<td>475</td>
<td>1331</td>
<td>1888</td>
<td>2619</td>
<td>3478</td>
<td>5026</td>
<td>5779</td>
</tr>
<tr>
<td>Main survey</td>
<td>131</td>
<td>298</td>
<td>391</td>
<td>509</td>
<td>625</td>
<td>842</td>
<td>1000</td>
</tr>
<tr>
<td>Uncompleted (Incidence &amp; Main survey)</td>
<td>505</td>
<td>1036</td>
<td>1400</td>
<td>2263</td>
<td>2604</td>
<td>2995</td>
<td>3622</td>
</tr>
</tbody>
</table>
Table 8.4: Comparison of key-indicators of the survey with Singapore statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Singapore statistics</th>
<th>Entire survey (Movers &amp; non-movers)</th>
<th>Incidence survey (Non-movers)</th>
<th>Main survey (Movers)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total population</td>
<td>5,534,990</td>
<td>-</td>
<td>6,905</td>
<td>-</td>
</tr>
<tr>
<td>Singapore citizens + Permanent residents</td>
<td>3,902,690</td>
<td>-</td>
<td>6,661</td>
<td>-</td>
</tr>
<tr>
<td>Singapore citizens</td>
<td>3,375,000</td>
<td>86.5%</td>
<td>6,043</td>
<td>90.7%</td>
</tr>
<tr>
<td>Permanent residents</td>
<td>527,700</td>
<td>13.5%</td>
<td>618</td>
<td>9.3%</td>
</tr>
<tr>
<td>Employment pass holders, and other passes</td>
<td>1,632,300</td>
<td>-</td>
<td>231</td>
<td>-</td>
</tr>
<tr>
<td>Number of households</td>
<td>1,225,300</td>
<td>-</td>
<td>6,906</td>
<td>-</td>
</tr>
<tr>
<td><strong>Gender [persons]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>1,986,060</td>
<td>50.9%</td>
<td>3,615</td>
<td>52.3%</td>
</tr>
<tr>
<td><strong>Ethnicity [persons]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinese</td>
<td>2,900,010</td>
<td>74.3%</td>
<td>5,844</td>
<td>84.6%</td>
</tr>
<tr>
<td>Malay</td>
<td>520,920</td>
<td>13.3%</td>
<td>423</td>
<td>6.1%</td>
</tr>
<tr>
<td>Indian</td>
<td>354,950</td>
<td>9.1%</td>
<td>402</td>
<td>5.8%</td>
</tr>
<tr>
<td>Others</td>
<td>126,810</td>
<td>3.2%</td>
<td>236</td>
<td>3.4%</td>
</tr>
<tr>
<td><strong>Household size [households]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 person households</td>
<td>146,000</td>
<td>11.9%</td>
<td>332</td>
<td>4.8%</td>
</tr>
<tr>
<td>2 person households</td>
<td>259,200</td>
<td>21.2%</td>
<td>1,026</td>
<td>14.9%</td>
</tr>
<tr>
<td>3 person households</td>
<td>256,200</td>
<td>20.9%</td>
<td>1,553</td>
<td>22.5%</td>
</tr>
<tr>
<td>4 person households</td>
<td>282,200</td>
<td>23.0%</td>
<td>2,172</td>
<td>31.5%</td>
</tr>
<tr>
<td>5 person households</td>
<td>164,000</td>
<td>13.4%</td>
<td>1,149</td>
<td>16.6%</td>
</tr>
<tr>
<td>&gt;= 6 person households</td>
<td>117,600</td>
<td>9.6%</td>
<td>674</td>
<td>9.8%</td>
</tr>
</tbody>
</table>
Table 8.5: Comparison of key-indicators of the survey with Singapore statistics (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Singapore statistics</th>
<th>Entire survey (Movers &amp; non-movers)</th>
<th>Incidence survey (Non-movers)</th>
<th>Main survey (Movers)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td><strong>Dwelling type [households]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDB</td>
<td>981,100</td>
<td>80.1%</td>
<td>5,417</td>
<td>78.4%</td>
</tr>
<tr>
<td>HDB 1- And 2-Room Flats</td>
<td>68,800</td>
<td>5.6%</td>
<td>167</td>
<td>2.4%</td>
</tr>
<tr>
<td>HDB 3-Room Flats</td>
<td>223,400</td>
<td>18.2%</td>
<td>975</td>
<td>14.1%</td>
</tr>
<tr>
<td>HDB 4-Room Flats</td>
<td>392,300</td>
<td>32.0%</td>
<td>2,324</td>
<td>33.7%</td>
</tr>
<tr>
<td>HDB 5-Room And Executive Flats</td>
<td>295,800</td>
<td>24.2%</td>
<td>1,951</td>
<td>28.3%</td>
</tr>
<tr>
<td>Condominiums and apartments</td>
<td>170,800</td>
<td>13.9%</td>
<td>990</td>
<td>14.3%</td>
</tr>
<tr>
<td>Landed property</td>
<td>69,200</td>
<td>5.7%</td>
<td>427</td>
<td>6.2%</td>
</tr>
<tr>
<td>Other types of property</td>
<td>4,200</td>
<td>0.3%</td>
<td>72</td>
<td>1.0%</td>
</tr>
<tr>
<td><strong>Ownership</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owner-Occupied</td>
<td>1,112,400</td>
<td>91.3%</td>
<td>6,081</td>
<td>91.9%</td>
</tr>
<tr>
<td>Fully paid for</td>
<td>-</td>
<td>-</td>
<td>3,054</td>
<td>-</td>
</tr>
<tr>
<td>With housing loan</td>
<td>-</td>
<td>-</td>
<td>3,027</td>
<td>-</td>
</tr>
<tr>
<td>Tenant</td>
<td>106,200</td>
<td>8.7%</td>
<td>535</td>
<td>8.1%</td>
</tr>
<tr>
<td>Provided free by parents/relatives/friends/others</td>
<td>-</td>
<td>-</td>
<td>275</td>
<td>-</td>
</tr>
<tr>
<td>Provided with subsidies or free by employers</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td><strong>Region [persons &gt;= 20 years old]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central region</td>
<td>760,460</td>
<td>24.9%</td>
<td>1,697</td>
<td>24.6%</td>
</tr>
<tr>
<td>East region</td>
<td>546,200</td>
<td>17.9%</td>
<td>1,162</td>
<td>16.8%</td>
</tr>
<tr>
<td>North region</td>
<td>403,830</td>
<td>13.2%</td>
<td>847</td>
<td>12.3%</td>
</tr>
<tr>
<td>North east region</td>
<td>648,010</td>
<td>21.2%</td>
<td>1,633</td>
<td>23.6%</td>
</tr>
<tr>
<td>West region</td>
<td>699,170</td>
<td>22.9%</td>
<td>1,567</td>
<td>22.7%</td>
</tr>
</tbody>
</table>

* Survey contained a further breakdown of tenure
entire survey’. The non-resident population forms a highly diverse group where an exact breakdown is outside of the scope of this chapter. Compared with the household survey, respondents were more likely to be Singapore citizens and more likely to be female.

Singapore’s society has evolved from migration from nearby countries China, Malaysia, Indonesia and India into a multiracial society. In population censuses, respondents are classified into four main ethnic categories: Chinese, covering persons of Chinese origin, Malay, covering persons of Malay and Indonesian descent, Indians, covering all people from the Indian subcontinent (including Indians, Pakistani, and Bangladeshi) and "Others", covering all the other ethnic groups, including Europeans, Eurasians, Filipinos, Japanese and Americans. Participants in the survey were more likely to be Chinese, and less likely to be Malay or Indian than in the general household survey.

Respondents are less likely to live in households consisting of 1 or 2 persons and more likely to live in households consisting of 4 or 5 persons as compared to the general household survey. Compared to the general household survey, respondents are as likely to reside in the three main dwelling types: HDB, condominiums and apartments and landed property. However, respondents are less likely to reside in HDB 1- or 2-Room flats, HDB 3-Room flats, as likely to reside in HDB 4-Room flats and more likely to reside in HDB 5-Room flats. Respondents are as likely to own or rent a flat. Singapore’s population statistics reveal that households residing in smaller flats are more likely to have an older household head; an increasing percentage of households from 50 years onwards tends to live in HDB 1 and 2-Room flats.

Singapore is divided into 5 planning regions, 55 urban planning areas and over 300 sub-zones by the Urban Redevelopment Authority (URA). In the survey, respondents were asked to select the area they reside in. To aid the respondent, a map was provided on which the planning area could be selected; by hovering over the map of planning areas, the names of the planning areas were revealed. The responses have been aggregated to five planning regions shown in Table 8.4: The geographic distribution of respondents is similar to the distribution found in the general household survey.

Figure 8.1 depicts the population pyramid of the Singapore population and the respondents. Singapore’s population pyramid is typical for a
developed nation with a slow to stagnating population growth. Compared to Singapore’s population, respondents are more likely to be young (younger than 39) and less likely to be old; a tipping point can be observed around persons aged 45-49. Furthermore, the figure reveals that young respondents are more likely to be female; older respondents are more likely to be male.

The respondents’ household income is compared to the household income as found in the general household survey in Figure 8.2. Respondents are less likely to have no household income, but more likely to fall into income categories between S$2,000 and S$8,000. Respondents are less likely to
8.5 Conclusion

This chapter presented the survey that was developed to investigate residential mobility and location choice in Singapore. The survey was split into two parts: the first part of the survey was aimed at the entire population; the second survey was aimed at respondents having moved in the three years prior to the survey. To reach 1,100 completed surveys by respondents having moved in the three years prior to survey conduct, it was necessary to reach 7,000 households. This results approximately in an incidence rate of movers in the panel of 16%, or 5% per year.

The share of Singaporeans versus permanent residents is slightly higher in the survey as compared to the general population. Furthermore, the share of respondents living in 4 and 5 person households is larger as compared to the general population. In line with this finding is the fact that the share of households living HDB 4-Room and HDB 5-Room flats is slightly higher among survey respondents than in the general population. The
percentage of respondents residing in the three main property types (HDB, condominium, landed property) is in line with the percentage across these three property types in general population.

When conducting a subsequent survey in Singapore introducing quota’s on age and household size would be an option. In this case, it was chosen not to introduce quota’s as the number of movers was not known prior to conducting the survey. Introducing quota’s could result in an overall too low number of respondents in the main survey.

However, given the totals for household size and dwelling type provided by the Department of Statistics it is also possible to calculate weights and correct for the oversampling of certain household strata. Results from Shaw et al. (2016) show that the calculated weights are in line with the findings of this descriptive analysis.

In the following chapters the survey results will be analysed in more detail. Chapter 9 will continue with an analysis of movers and non-movers in Singapore; Chapter 10 presents findings on the search for a new residence. Chapter 11 provides more detail on the eventual choice for a new residence.
Chapter 9

Residential mobility in Singapore

9.1 Introduction

The decision to become active on the residential market, whether due to adjustment, induced or forced reasons, is the starting point of residential mobility. Whereas in the well-established two stage model of residential mobility (e.g. Brown and Moore, 1970) the choice to move and the choice for a subsequent dwelling are seen as two distinct consecutive phases, in the three stage conceptualization of residential mobility a distinction between (1) the decision to move, (2) the search for a suitable dwelling and (3) the final choice whether to move or not to move into the chosen dwelling (e.g. Mulder, 1996). Despite the differences in the conceptualization of the moving process, both models stress the importance of the decision to move.

Several statistical methods can be found in literature to quantitatively assess residential mobility, varying from logistic regression (de Groot et al., 2011; e.g.), discrete choice models (e.g. Clark and Huang, 2003; Habib, 2009; Lee and Waddell, 2010) and hazard-based models (e.g. van der Vlist et al., 2002; Habib, 2009). Hazard-based models calculate the likelihood of moving based on the time from the last occurrence, and take into account other independent variables. However, this assumption falls short to account for the household formation process: moves not only occur because of changes in life cycle of households, but also because young adults leave the parental home, either to live alone or with a partner (Mulder and Hooimeijer, 1999).

This chapter focuses on differences between households who moved
house and households who did not move house in Singapore in the period from 2013 to 2016. These differences are assessed by means of a descriptive analysis of the survey presented in the previous chapter, followed by a discrete choice model describing the combined choice to move, tenure and property market.

The remainder of this chapter is outlined as follows. Section 9.2 presents a descriptive analysis of movers and non-movers in Singapore. Section 9.3 looks closer into the intentions to move. Section 9.4 continues with an analysis of movers in Singapore. Section 9.5 presents the combined model to move, tenure choice and choice of property market. Concluding remarks are given in section 9.6.

### 9.2 Movers versus non-movers

**Socio-demographics**

To assess the differences between respondents who moved house in the three years prior to the survey and respondents who did not move house, a comparison of their demographics is provided in Table 8.4. Respondents who have moved house were more likely to be permanent residents or work pass holders as compared to respondents who did not move house. Respondents who have moved house were more likely to be of Indian descent and less likely to be of Chinese descent.

**Dwelling type**

Respondents who moved house were more likely to be part of households consisting of 2 or 3 persons and less likely to live in households consisting of 4 or 5 persons as compared to respondents who did not move house. A closer inspection of these respondents is required to determine whether this concerns people starting their residential career and / or a family, or whether this concerns households moving house after one or more household members have left the house.

**Tenure**

Surprisingly, respondents who moved house were less likely to reside in a owner-occupied dwelling and more likely to rent their dwelling. Furthermore, they were less likely to have their housing loan fully paid for.

**Location**

Respondents who have moved house are more likely to reside in the
North-East region and less likely to reside in the East region. Figure 9.1 provides a more detailed spatial overview of respondents who moved house (main survey) and respondents who did not move house (incidence survey); depicted is the percentage of respondents per planning area for each survey individually. Respondents who moved house were more likely to live in the planning areas Sengkang, Punggol, two HDB towns that have witnessed a tremendous amount of construction, and to a lesser extent Hougang.

**Household composition**

In line with the Singapore general household survey, respondents were asked whether they were part of couple-based household or whether they were living alone. A priori it could not be ascertained which member of the household would take part in the survey. Therefore, respondents were asked to select which statement described their household best; multiple statements could be selected by the respondent. Less than 5% of the respondents selected multiple options.

The responses to these questions are shown in Figure 9.2. The majority of the respondents was living a partner, living in their parents home, or had parents living in their home; respondents who were living with partner were more likely to move house than respondents living with their parents.
Figure 9.2: Description of household in the incidence survey (non-movers) and main survey (movers)

Figure 9.3 shows a second classification: Respondents who recently moved house were more likely to be couples without children; couples with children were as likely not to move house.

A further classification of the respondent’s household members was possible by using the relationship of the respondent to each household member. The result of this analysis is shown in Figure C.2 (Appendix C). Respondents live with their partner/spouse and son/daughter, in line with the two earlier classifications that were shown. Respondents living with their partner/spouse were more likely to move. Respondents living with parents and siblings were less likely to move.

Figure C.1 (Appendix C) depicts the respondent’s age when moving into the current dwelling; negative age interval indicate that the respondent’s parents were living in the current dwelling prior to starting a family. In line with trends in Western countries, most respondents between 25 and 35 exhibit the highest residential mobility. However, respondents aged between 35 and 40 were still highly likely to move house.

As the year of birth was asked for each household member, it is possible to calculate the age for each household member. Figure 9.4 depicts whether the respondent’s household had one or more members within a certain
age group, at the time of the survey; the respondent is included in the classification. Households with members aged between 0 and 9 as well as members aged between 25 and 34 were more likely to have moved house in the period 2013 - 2016.

### 9.3 Intentions to move

A large proportion of households with the intention to move does so within two years of having this intention (e.g. de Groot et al., 2011). To investigate these intentions to move an additional distinction was made between the commitment made to move house by purchasing a dwelling with the intention of living there, i.e. making an advance purchase, and the intentions to move house without the commitment to purchase the dwelling.

For Singapore it is found that 25% of the respondents who stated not to have moved house in the period 2013 - 2016 did make an advance purchase. Additionally, it is found that 37% of the respondents who stated to have moved house in this period had made an advance purchase. The implications of this finding will be discussed in the next chapter.
Almost 60% of the households who made an advance purchase plan to live in the dwelling as a couple with children, whereas 20% describes their household as a couple without children. Over 35% of the respondents who planned to live in their next dwelling as couples without children are currently living with their parents; over 21% of the respondents who plan to live in their next dwelling plan as couples with children currently lives with their parents. These figures indicate that households leaving the parental home to form a new household who made to a large extent an advance purchase.

Continuing with the households who did not make an advance purchase, it is found that over 50% who did not move house in the period 2013 - 2016 have no intention of moving, 8% of the respondents state to most certainly move, almost 30% state to probably move and slightly less than 10% states that they want to move, but cannot find a dwelling meeting their criteria. Combined with the number of households that made an advance purchase, over 61% who did not move house in the period 2013 - 2016 have intentions to move house, in line with figures cited by de Groot et al. (2011).

The desire to own a home plays a highly important role in the intentions
to move; 93% of the respondents who have intentions to move wish to purchase a dwelling; the remaining 7% indicated they wanted to rent a dwelling.

A closer look at respondents who did not make an advance purchase and do not have further intentions to move: 40% of the respondents state that they were satisfied with their dwelling; 13% indicating not wanting to move away from their current neighbourhood. However, over 32% of the respondents mentions that, despite having no intentions to moving, that moving is too expensive, they cannot find a suitable dwelling, consider the property market not promising, or are not eligible to buy an HDB flat; mostly reasons related to different aspects of the residential market.

9.4 Movers

9.4.1 Changes in household composition

In an analysis of household changes before and after moving house, it was found that over 56% of the respondents indicate that all members of the current household lived with them at their previous dwelling; 23% of the respondents indicate that one household member was different, 10% indicates that two or more household members were different.

The respondent’s relationship to household members that have joined and left the household since the move to the current dwelling is shown in Figure 9.5: In line with the findings in the previous section concerning the advance purchase of a dwelling, household members most likely not be part of the household since the move include parents and parents-in-law and other relatives; partners and children were most likely to be part of the household after the move. Whereas the first finding clearly related to the formation of a household, the second finding is closely related to the change in life cycle.

9.4.2 Household classification

To classify households who participated in the survey of movers, two types of classifications were investigated. The first classification derived changes in household composition from the survey. However, given the distinct property market segments in Singapore and the requirements to enter certain
segments, a classification of respondents based on type of tenure and type of dwelling was made.

Classification based on life cycle stage
The classification aiming to make a distinction on life cycle stages was made based on whether respondents were living with their parents at their previous dwelling, and whether they were either living with parents, partner and/or children in their current dwelling (Table C.1).

This classification resulted in 14 classes in 3 main categories: (1) nest-leavers, respondents previously living with parents, (2) upgraders, respondents previously and currently not living with parents, and (3) respondents or parents living reunited after the move. A second dimension was introduced by considering household composition: (1) a single person household, (2) a single parent household or (3) a couple-based household.

This classification showed that couple-based nest-leavers and upgraders form the majority of the recent movers. Both groups accounted for 30% of the moves. Households consisting of parents and couples account for another 8% of the moves. Single-person upgraders account for 8.8% of the moves, whereas single-persons nest-leavers only account for 4.4% of the moves.
Classification based on dwelling & tenure

Recent movers can also be classified according to their chosen dwelling type. Decision-makers are classified according to a series of characteristics: the type of dwelling respondents state they are currently living in, the tenure and whether they purchased a flat for the first time. By enumerating these characteristics the following classification is obtained:

- **HDB New sale - First timer**: Respondents who have moved to HDB projects constructed under the build-to-order (BTO) scheme and the Design, Build and Sell Scheme (DBSS) and have purchased an HDB flat for the first time (240 respondents, 27%).

- **HDB New sale - Second timer**: Respondents who have moved to HDB projects constructed under the BTO scheme and DBSS and have not purchased an HDB flat for the first time (70 respondents, 7.8%).

- **HDB Resale - First timer**: Respondents who have moved to HDB resale flats and have purchased an HDB flat for the first time (158 respondents, 17.6%).

- **HDB Resale - Second timer**: Respondents who have moved to to HDB resale flats and have not purchased an HDB flat for the first time (107 respondents, 11.8%).

- **HDB - Rental**: Respondents who have moved to an HDB rental flat (198 respondents, 22%).

- **Private - Sale**: Respondents who have purchased a flat on the private market (230 respondents, 25.6%).

- **Private - Rental**: Respondents who have rented a flat on the private market (81 respondents, 9%).

To compare this dwelling based classification versus the earlier discussed of households, a cross tabulation has been made, which is presented in Figure C.3; column sums equal 100%. Nest-leavers (couples) mainly opt for HDB new Sale (45%), followed by HDB resale and private sale. Upgraders (parents & couples) also opt for HDB new Sale. This can indicate that couples were living with their parents / parents-in-law, and purchased an HDB BTO flat, but were waiting for completion.

In the ensuing analysis a differentiation will be made on the classification by dwelling type & tenure, as this classification showed clearer differences in behaviour.
9.4.3 Tenure changes

The difference between current and previous dwelling were analysed by means of the change in dwelling type, the change in tenure, the change in floor area and the change in distance to employment and education.

Figure 9.6 highlights the previous tenure and the current dwelling type and tenure. Owner-occupied tenure is aggregated from ‘owner-occupied, fully paid for’ and ‘Owner-occupied, with housing loan’. Tenure ‘other’ is aggregated from ‘provided with subsidies or free by employers’ and ‘provided free by parents/relatives/friends/others’. Singapore’s high home ownership rates are reflected in Figure 9.6. Respondents purchasing HDB New sale for the first time or HDB resale for the first time either originate from owner-occupied property (50%) or tenures other than rental (30%-40%). Respondents purchasing HDB New sale or HDB Resale for the second time mainly originate from owner-occupied properties (approximately 80%). Conversely, respondents currently living in rental mainly remain in HDB rental dwellings (76%). Slightly more mobility between owner-occupied housing and private rental can be observed (32%), however the majority stems or tenants stem from private rental.

9.4.4 Push reasons

For recent movers we examined the reasons to move from their previous dwelling (push reasons). A distinction was made between reasons related to household composition and other major reasons. Figure 9.7 presents the push reasons related to changes in the household composition.

Half of the respondents indicated that their move was not the result of household changes; approximately 30% of the of the respondents indicated that marriage or living with a partner was a reason for moving house; however, variations can be observed between the different groups of movers. Respondents moving to HDB new sale, and HDB resale, for the first-time indicate that marriage was the most important reason related to the life cycle. Lifecycle reasons seem to be of less importance when households move for the second time or more.

An overview of other push reasons is given in Figure 9.8. A change in financial situation and a change in employment location were among the reasons for moving house; the latter category is prominent among respondents opting for HDB and private dwellings on the rental marker,
Figure 9.6: Previous tenure to current dwelling type / tenure. Columns sum up to 100%.

Rather surprising is the prominence of the reasons 'other'. Respondents not satisfied with the previous dwelling’s environment were mainly respondents moving to the HDB resale market. Closer inspection of this free text field other revealed that the aspiration of home ownership was often mentioned.

Respondents who indicated that the previous dwelling was a reason for moving subsequently indicated that they either found their previous dwelling too small or that they preferred a different type of dwelling (Figure 9.9). Respondents who indicated that the previous dwelling’s environment was a reasons for moving subsequently indicated that the previous neighbourhood’s atmosphere did not appeal to them. Other frequently mentioned reasons include noisy neighbours, public transport not being close enough and the neighbourhood being too crowded.
Figure 9.7: Push reasons: life cycle

Figure 9.8: Push reasons other than life-cycle
Figure 9.9: Push reasons: dwelling

- The dwelling was too small
- The dwelling was too large
- You wanted to rent a dwelling
- You wanted a different type of dwelling
- The dwelling was badly insulated (noise)
- The dwelling was badly maintained
- Other

Figure 9.10: Push reasons: dwelling’s environment

- Too crowded
- Too quiet
- Neighbourhood badly maintained
- Noisy neighbours
- Neighbourhood atmosphere did not appeal to me
- Smells
- Noise of traffic
- Dust
- Garbage
- Not enough greenery
- Traffic safety
- Not close enough to public transport
- No parking available
- Other

Mentions


9.4.5 Pull reasons

In addition, we examined 26 reasons for respondents being attracted to their current dwelling (Figure C.4). The price and availability of the current dwelling were among the most frequently stated reasons; proximity to public transport and the respondent’s employment location was often mentioned as well. Respondents often stated that they were limited by the availability of HDB flats.

9.5 Modeling residential mobility

9.5.1 Methodology & model specification

Methodology
In order to analyze residential mobility further, a choice model is specified. This model is specified as a multi-level nested logit model. Within a nested logit model, the alternatives considered by a decision-maker are partitioned into subsets, or nests. For any two alternatives in the same nest, the probability of choosing an alternative is independent of the attributes of all other alternatives; IIA holds. For alternatives in different nests, the ratio of choosing that alternative can depend on the attributes of other alternatives in two nests (p. 77, Train, 2003).

Model specification
The upper-nest of the model represents the choice whether to stay or to move house. The nest ‘move’ is further partitioned by tenure (rental / ownership). The nest ‘owner’ is further partitioned by dwelling type (HDB / private). The nest ‘HDB’ is partitioned into ’New sale’ and ’Resale’. This model specification is also highlighted in Figure 9.11.

Model specification being an iterative process, several other nested structures were tested in the model estimation process. These model specifications included (1) a two-level nested logit specification where the subsets represented the decision to stay or move, as well as (2) a multi-level nested logit model that included a further specification by tenure. While model 2 did not prove to be better than model 1, judging by the log-likelihood test, the final model specification proved to outperform model 1 and a multinomial logit model.

In addition to the aforementioned alternatives, several other choice set
Figure 9.11: Tree diagram for residential mobility

specifications were considered in initial model estimations. These include: (1) the choice whether to move or stay, (2) the choice whether to stay, or to purchase or rent a dwelling, (3) the choice whether to stay, or to move to an HDB or private dwelling unit, and (4) the choice whether to stay, whether the respondent had intentions to move, and to move. Model specifications 1, 2, and 3 yielded significant parameter estimates but were considered not to fully capture Singapore’s residential market. Model 4 did not yield significant parameter estimates for the alternative describing the intention to move, indicating that these respondents were not different than respondents staying at their current dwelling.

Variable specification
The survey of movers in Singapore serves as a basis for the model estimations presented in this chapter. As this was a cross-sectional survey, special attention was paid to the composition of the household, the respondents’ dwelling type and the respondents’ dwelling characteristics at the time of move.

Furthermore, to be able to define similar attributes for respondents opting to stay and respondents opting to move, attributes were limited to questions asked in the incidence survey, and questions from the main survey concerning the previous residence. For respondents that have moved house, their age, and the age of fellow household members was calculated for the year of move. Household members born after the move (i.e. with a negative
age) were included in model estimations as lagged variables. For attributes describing household composition the household composition prior to the move to the new dwelling was taken into account.

The residential survey was enriched with a range of spatial variables. The overlapping level of spatial resolution between the incidence survey and the main survey was on the level of Singapore’s 55 planning zones. As such, spatial variables were calculated on this level of resolution.

### 9.5.2 Results & discussion

Table 9.1 reports the results of the final model describing the choice to move and dwelling / tenure type; model estimations were performed with Biogeme (Bierlaire, 2003); Table 9.2 reports the goodness-of-fit. The high adjusted Rho-square for the model is 0.658 is in line with the rare occurrence of a move as compared to not moving.

In line with evidence in literature, households with members between 25 and 39 years old are most active on the residential market (Dieleman, 2001; Clark and Huang, 2003). However, differences can be observed with regard to the choice of tenure and dwelling type within this age group. Households with members aged between 25 and 29 are more likely to opt for the rental market and less likely to purchase an HDB resale or private dwelling unit. Households with members aged between 30 and 34 are most likely to be move and opt for an HDB new sale dwelling unit, a result that is expected as it is line with residential policies in Singapore, whereas households with members aged between 35 and 39 are more likely to be move to a dwelling on the HDB resale or private market.

Single person households have a higher probability of opting for renting a dwelling, as opposed to purchasing a dwelling. It is hypothesized that is due the limitations that single person households have given their income, limiting the possibilities to purchase a dwelling. Second, residential policies in Singapore favour couple-based households for certain grants and schemes. Most notably, only a limited number of HDB New sale dwellings is available to single person households aged 35 years and over.

Clark et al. (1994) report that both families and couples are more likely to move to own in the United States; couples aged younger than 25 are more likely to move to own, whereas families between 35 and 44 are more likely to move (19\% vs 6\%). Couples and families between 25 and 34 are
### Table 9.1: Nested logit model of residential mobility

<table>
<thead>
<tr>
<th></th>
<th>Stay Est. (t-test)</th>
<th>Move Rental Est. (t-test)</th>
<th>HDB New Sale Est. (t-test)</th>
<th>HDB Resale Est. (t-test)</th>
<th>Private Est. (t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Members aged (Yes / No)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 0 and 4</td>
<td>0.249 (3.85)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 5 and 9</td>
<td>0.407 (5.07)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 25 and 29</td>
<td></td>
<td>1.18 (3.09)</td>
<td></td>
<td>-0.74 (-2.7)</td>
<td>-0.74 (-2.7)</td>
</tr>
<tr>
<td>Between 30 and 34</td>
<td></td>
<td></td>
<td>0.763 (4.44)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 35 and 39</td>
<td></td>
<td></td>
<td></td>
<td>0.281 (2.15)</td>
<td></td>
</tr>
<tr>
<td>Over 60 years old</td>
<td></td>
<td></td>
<td></td>
<td>0.281 (2.15)</td>
<td>1.31 (5.98)</td>
</tr>
<tr>
<td><strong>Composition</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Single</td>
<td>2.43 (6.05)</td>
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<td></td>
</tr>
<tr>
<td>Couple without children</td>
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<td>1.24 (3.43)</td>
<td></td>
<td>0.81 (2.89)</td>
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</tr>
<tr>
<td><strong>Household monthly income</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Up to SGD 4,000</td>
<td>0.824 (1.89)</td>
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<tr>
<td>SGD 4,000 - SGD 8,000</td>
<td>0.653 (1.85)</td>
<td>1.2 (2.94)</td>
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<td></td>
</tr>
<tr>
<td>SGD 8,000 - SGD 12,000</td>
<td>1.52 (4.62)</td>
<td>2.07 (5.32)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than SGD 12,000</td>
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<td>3.34 (5.93)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tenure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owner</td>
<td>1.1 (25.83)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dwelling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room stress</td>
<td>0.763 (8.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spatial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to CBD [km]</td>
<td></td>
<td></td>
<td></td>
<td>0.059 (2.29)</td>
<td></td>
</tr>
<tr>
<td><strong>Constants</strong></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Alternative constant</td>
<td>-3.44 (-2.75)</td>
<td>-5.04 (-3.07)</td>
<td>-5.09 (-2.78)</td>
<td>-3.48 (-4.68)</td>
<td></td>
</tr>
</tbody>
</table>
Table 9.2: Nested logit model of residential mobility: nest parameters and goodness of fit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nest parameters</strong></td>
<td></td>
</tr>
<tr>
<td>Move / stay</td>
<td>0.407 (3.48)</td>
</tr>
<tr>
<td>Rental / Owner</td>
<td>0.684 (5)</td>
</tr>
<tr>
<td>HDB / Private</td>
<td>0.185 (2.31)</td>
</tr>
<tr>
<td><strong>Goodness-of-fit</strong></td>
<td></td>
</tr>
<tr>
<td>Final log-likelihood</td>
<td>-3753.744</td>
</tr>
<tr>
<td>Adjusted rho-square</td>
<td>0.658</td>
</tr>
</tbody>
</table>

even likely to move (51% resp. 56%). The descriptive analysis of movers in Singapore revealed that families with children are as likely to move and stay; a finding which is confirmed by the model estimations. However, it is found that couples without children are more likely to move to HDB New sale flats and private dwellings. Furthermore, households with children aged between 0 and 4, and 5 and 9, are more to remain in their current dwelling, similar to Lee and Waddell (2010). This finding indicates that couples tend to settle prior to starting a family and are less inclined to adjust housing consumption. Habib (2009) introduced lagged variables describing the number of children born in a family after moving house to capture the perspective of couples to start a family at the moment of making the decision to move. Introducing similar variables for Singapore did not yield a significant parameter estimates.

The results for household income are in line with the differentiation of property types found in Singapore and restrictions on certain market segments. Households earning up to SGD 8,000 per month are more likely to move to rental units. To participate in the housing market as an owner, a higher income is required. Households within an income between SGD 8,000 and SGD 12,000, followed by households with an income between SGD 4,000 and 8,000 are more likely to purchase an HDB new sale dwelling. In addition the capital requirements for purchasing a dwelling these estimates also show the restrictions on purchasing an HDB New sale dwelling. Households with an income above SGD 12,000 are excluded from the HDB New sale market.
Empirical evidence in literature shows that renters are more likely to move house than households owning a dwelling (e.g., Dieleman et al., 2000). Singapore is no exception to this rule: the positive parameter for ownership in the stay alternative shows that respondents residing in owner-occupied dwellings are more likely to stay.

The distance to the central business district was found to be significant for households moving to HDB resale flats. The positive parameter indicates that households residing further from the CBD are more active on the HDB resale market, which can indicate that they want to reside closer to the CBD. Other spatial variables, such as job housing balance, percentage commercial area in the planning area, percentage of parks in the planning area and land-use mix of the planning area were not found to be significant in the decision to move.

9.6 Conclusion

This chapter presented a descriptive analysis as well as a combined model of residential mobility, tenure and residential market for the Singaporean residential market. The nested model for different property types was chosen because of the difference that can be observed in pull and push reasons as well as the differences in property market segments.

The descriptive analysis as well as the model estimations were based on the residential survey presented in the previous chapter, which was an online cross-sectional survey with a series of retrospective questions.

Model estimations show that couples without children are more likely to purchase an HDB New sale dwelling and to a lesser extent a dwelling on the private market. Single person households are most likely to rent a dwelling. In line with evidence in the literature owners are less likely to move. Households opting for an HDB resale dwelling are more difficult to distinguish from households staying at their current location. These households more likely consist of adults aged between 35 and 39 and showed to prefer to reside closer to the CBD. These moves are more likely to be moves resulting from reasons to adjust housing consumption. Residential location choice models geared for HDB resale properties can provide more insight in what drives the choice for location, which then can provide insight in reasons for mobility. Nevertheless, findings are mostly in line with the
Chapter 9. Residential mobility in Singapore

findings from residential mobility studies conducted for Europe and the United States. If a difference should be pinpointed, this difference can be the presence of children; whereas studies conducted in Europe have shown that mobility rates are high for couples with children and without children, in Singapore couples without children tend to move and form a family after moving house.

Residential mobility is one of the driving forces of urban dynamics. In Singapore it is found that 35% of the moves are towards newly built HDB dwellings, whereas almost 30% of the households opt for a dwelling on the HDB resale market. It is safe to say, that in Singapore the Housing Development Board is one of the driving forces of urban dynamics. The high share of moves to HDB new sale dwellings, combined with the model findings that couples without children and owners move less, makes planning decisions by the Housing Development Board detrimental for households entering a new life cycle stage and starting their residential career.

This chapter has not analysed the advance purchase and the intentions to move beyond the descriptive analysis. A second model could provide more insight in households with intentions to move.
Chapter 10

Residential search in Singapore

10.1 Introduction

Once households have expressed their desire to move house, the search for a suitable dwelling commences. As concluded in the literature review in Chapter 7, this search process is characterized by a temporal component (i.e. the period of time households have available), the households’ preferences with regard to the dwelling (e.g. size, number of rooms, price), the households’ preferences with regard to the location (e.g. proximity to work, proximity to schools), and the households’ constraints (e.g. affordability). The search process results in a set of dwellings that the household considers in their eventual choice for a dwelling.

Given the large number of potential residential alternatives on the residential market, researchers have sought ways to characterize the choice set formation process, a behavioural process and/or to constrain the choice set by means of choice set generation, a statistical procedure. Traditionally, research has paid more attention to the choice set generation process than the choice set formation approach. An exception can be found in the work of Zolfaghari et al. (2012), who approach the choice set formation process by introducing price and distance to employment constraints. Huff (1986) finds that households search patterns are spatially restricted; Barrett (1976) finds that households only examine a limited number of properties.

This chapter investigates choice set formation and generation for Singapore. Section 10.2 continues with the revealed search preferences. As choice models will be estimated on the level of individual dwelling units.
Section D.2 describes the matching of chosen dwellings, as given in the residential survey, with actual transactions, a necessity to generate choice sets for survey respondents. Section 10.3 presents the results of the choice set generation process. Finally, in section 10.4 concluding remarks are presented.

10.2 Search preferences

To obtain insights in a household’s preferences when they commenced upon the search for their desired dwelling, respondents were asked a number of questions concerning the household’s search criteria. Among others, criteria for the type of dwelling, type of tenure, and location were asked for; this section investigates these preferences.

10.2.1 Dwelling characteristics

Purchase price

Affordability is one of the drivers in the choice for a new dwelling; Figure 10.1 provides an overview of the minimum, ideal and maximum price considered by households at the beginning of their search for a new dwelling by chosen dwelling type; the results are visualized as a box-plot. Households who opted to rent a dwelling are included in this analysis if they were considering to purchase a dwelling.

Households who have opted for an HDB new sale flat for the first time consider a narrower range than households considering an HDB New sale flat for the second time. However, both groups prefer a similar average price. The minimum average price amounted to approximately S$225,000, the ideal price hovered around S$250,000 and the maximum average price is slightly higher than S$500,000.

From all households, households who moved to HDB rental flats considered flats in the lowest price ranges. On average, they were considering flats of approximately S$175,000.

Households who moved to private dwellings were willing to purchase a dwelling for S$800,000 (ideal price). The wide price ranges for the minimum, ideal and maximum sales prices indicates the heterogeneity of both the dwellings in the market and purchasers’ preferences.
Households opting for a dwelling in the private rental market were considering dwellings in wide price range, varying from S$300,000 as an average minimum price up to S$600,000 as an average maximum sales price.

**Number of rooms**

Households who purchased an HDB new sale flat for the first-time, as well as households who opted to rent an HDB or private flat are looking for a smaller house than respondents who purchase an HDB flat from the resale market. For instance, households opting for HDB New sale for the second are drawn towards flats with a minimum of 2 rooms; households opting for HDB New sale for the first time, as well households opting for an
HDB resale flat are drawn to towards dwelling with a minimum of 3 rooms. Households opting for an HDB rental flat are looking for units with either 1 or 2 rooms.

These results are shown in Figure D.1 in Appendix D.2, which highlights the minimum, ideal and maximum number of rooms respondents considered in their prospective dwelling. In addition, the difference between the minimum and maximum number of rooms is depicted.

**Floor**
Households who moved to an HDB or private rental flat indicate to have no clear preference for a certain floor level. Households who moved to a private flat also indicate having no preference. This can indicate the heterogeneity of the supply of private flats, as opposed to the homogeneous character of HDB flats. Households moving to an HDB New sale clearly have a preference for flats for flats located on higher floor levels. This relationship is shown in more detail in Figure D.2 in Appendix D.2.

### 10.2.2 Search process

**Considered markets**
An overview of the considered markets by households who purchased a dwelling is presented in Figure 10.2. Households who moved to HDB new sale apartments have considered mostly the HDB new sale market, and to a lesser extent the HDB resale and private market. A similar, but less pronounced effect can be observed for households who have moved to HDB resale flats: most respondents solely consider HDB resale flats, but several households express a preference for HDB new sale and private dwellings. In addition, these households consider private dwellings, especially respondents who purchased an HDB flat previously. Household who have moved to a private sales flats are more likely to only consider dwellings on the private market.

**Considered areas**
Households were asked to select the areas they considered for each of markets they expressed an interest in; respondents had the possibility to select multiple areas. These markets could be one or more of the following: HDB new sale, HDB resale, private sale and rental dwellings. Figure 10.3 shows the areas considered by respondents. Households expressing interest in HDB new sale flats selected areas in the North East of Singapore:
Punggol, Sengkang and Ang Mo Kio. These are the areas that have seen the highest number of HDB BTO projects over the last decade. Households expressing an interest in the HDB resale market selected areas more central areas: Ang Mo Kio, Bishan, Serangoon, Hougang, Toa Payoh, Bedok and the mature estate Tampines. These areas contain HDB towns that have been developed over in the last decades and are considered HDB mature towns: these towns are considered to have more amenities, as well as the possibility that social contacts such friends and family live here. In contrast, households expressing an interest in private flats selected areas spread out over Singapore. Notable differences in the selected areas as compared to the selected areas for HDB new sale and resale flats include Marine Parade (located on the south side of Singapore, also known as East Coast), and areas located in the south-west of Singapore: Bukit Timah, Queenstown and Clementi. Households expressing an interest in the rental market revealed to prefer the same areas as households expressing an interest in private dwellings; no distinction was made between HDB rental and private rental in the questionnaire.
Figure 10.3: Considered areas at the start of the search for a new dwelling

(a): HDB New Sale  (b): HDB Resale

(c): Private  (d): Rental

Figure 10.4 shows the number of areas considered. Almost 60% of the households expressed an interest in HDB new sale dwellings considered a single area, whereas 50% of the households who expressed an interest in the HDB resale and/or private sales market considered one area.

Geographic dispersion

To further quantify the search extent of households a second measure is be calculated: the geographical dispersion of the areas considered by each household. To these means, the standard distance is calculated (e.g. ESRI, 2017), a variation on the well-known standard deviation. The standard distance provides a single value representing the dispersion of values around
Figure 10.4: Number of areas per considered market, and total

\[
SD = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{X})^2}{n} + \frac{\sum_{i=1}^{n} (y_i - \overline{Y})^2}{n}} \tag{10.1}
\]

where \(x_i\) and \(y_i\) represent the coordinates of the centroid of the area, \(\overline{X}\) and \(\overline{Y}\) are the mean values, and \(n\) represents the number of areas considered.

Figure 10.5 shows the calculated standard distances per set of markets considered by recent movers. Households considering a single market (i.e. HDB new sale, HDB resale and private) reveal to have the lowest standard distance, the extreme case being recent movers only considering HDB new sale. Not coincidentally, they expressed interest in the lowest number of areas (Figure 10.4).

Households considering either HDB resale or private property reveal to have an average search distance of approximately two kilometres, indicating that the considered areas are in close proximity. Households considering a combination of two markets (HDB new sale & HDB resale, HDB resale & Private) reveal to have an average search distance of approximately four
kilometres. It is hypothesized that this difference is the result of the spatial separation of HDB new sale dwellings, typically located in newly built towns, and the other property types, which are built as infill development. The limited standard distance for households considering HDB resale and private property shows that a large number of households selects areas in close proximity to each other, and that these areas offer both types of property.

**Search duration**

To investigate the temporal dimension of the residential search process households were asked to state how long they were active on the residential market; the results are highlighted in Figure 10.6. Households who balloted for a new HDB flat spent most time searching for their current dwelling; these households spent on average six months on the residential market. Households who have opted for an HDB resale flat spent slightly less time on the residential market with an average search duration of four months. Households who decided to move to a private dwelling spent on average six months on the market. Households active either on the HDB or private rental market spent only two months searching for their dwelling.
Considered and visited properties

In addition to the extent of the area searched and the number of areas considered, households were asked to state the number of properties they considered, seriously considered and visited. This phrasing and sequence was explicitly chosen as it was thought that house seekers would first consider a dwelling and only then visit a dwelling.

Figure 10.7 shows the percentage of households stated to have considered, seriously considered and visited a certain number of properties. First, the different distributions show that the distinction between visit, seriously considered and visited is not immediately clear. The number of properties visited is higher than the number of properties considered and seriously considered. Second, it can be seen that rounding occurs: peaks can be observed at five and ten properties.

For all markets, the majority of the households indicates to consider and visit only one property, this trend being most pronounced for landed property. Also, for all markets it can observed that households visit up to four properties per market.
Figure 10.7: Number of areas properties considered, seriously considered and visited

Search channels
To investigate how households obtained information on dwellings households were asked to state the search channels they used; households could provide multiple answers. Figure D.3 highlights the used search channels; a break-down by chosen dwelling type is given.

Households who have opted for an HDB new sale flat mainly made use of the HDB website; the HDB website is the main location where information on the properties and application process is given. Households who have chosen HDB resale flats also use the HDB website, despite the limited amount of information it contains on available flats. Instead, information is provided on transacted prices and the proximity to amenities. For these households dedicated agents are the most important search channel, followed by usage of the internet. For households who moved to private dwellings, either sales or rental, the internet was the most popular method to gather information, followed by using a dedicated agent. Newspaper advertisements were still a popular search channel for households opting for a dwelling in the private sales market.

Search sequence
Over 60% of the households choose the most desirable location first, and
then could to find whatever type of housing they could afford. The remaining
40% stated to several locations they can afford first, and then choose among
these. Only for households opting for private rental properties this trend
was reversed.

**Most competitive alternative**

In addition to the search criteria and knowledge on the previous and current
dwelling, the most competitive alternative can provide additional insight
in the households’ search and choice behaviour. Figure 10.8 highlights
the reasons for considering this most competitive alternative (left) and
the reasons for not choosing the most competitive alternative (right); a
breakdown by the type of property is given.

Households considering HDB and condominium dwellings value the
proximity to amenities and transit most; respondents considering HDB
additionally value the proximity to family. On other hand, households
interested in landed property value the number of rooms and the size of the
unit most. Surprisingly, the proximity to child care and schools is of minor
importance.

The most prominent reason for not choosing the most competitive
dwelling is that the alternative is outside of the respondent’s price range;
this especially holds for condominiums. The dwelling not being available
any more is mentioned as a second reason.

10.2.3 Housing policies

**Ballot exercise**

Given the prevalence of HDB new sale as well as the affordability of HDB
new sale dwellings, an additional analysis of participation in the ballot for
HDB new Sale flats was made. Slightly less than 37% of the households
said to have participated in an HDB ballot exercise. Households who have
moved to HDB New sale dwellings for second time participate most often
in the ballot exercise; 20% of these respondents participated three times in
a ballot exercise. Apparently, these households are willing to wait longer
for a favourable flat. Around 60% of the respondents who have moved
HDB resale for the first and second time participate only once in the ballot
exercise. Households who opted for rental flats in the HDB and private
sector participate in the ballot exercise up to three times.

Households who moved to HDB resale and private flats opted not to
Chapter 10. Residential search in Singapore

Figure 10.8: Reasons for considering (left) and not choosing (right) the most competitive alternative

Figure 10.9: Number of ballots
-participate in the ballot for a variety of reasons. Over 50% households opting for dwellings in either the private or HDB rental market highlighted that they were not eligible for HDB New sale. Households who chose to purchase an HDB resale flat did not opt for an HDB New sale for three major reasons: (1) the waiting time was too long, (2) they did not like the location of the available estates, and (3) they were not eligible. This finding complements the finding that these respondents did not participate in the ballot often and a higher urgency of finding a new dwelling. Households opting for a dwelling on the private market on the other hand considered the probability of a favourable ballot outcome too low.

HDB Priority Programmes
The Housing Development Board has a range of policies and subsidies for households buying an HBD new sale and HDB resale flat. Over 55% of the respondents purchasing an HDB New sale flat, indicate not to have made use of a priority program. Two priority programmes were often used. Slightly less than 18% of the respondent made use of the Parenthood Priority scheme, a scheme put in place to give couples with children priority in the ballot procedure. Over 15% of the households make use of the Married Child scheme. This scheme helps a married child and parents to live close together; parents can live up to two kilometres from the flat.
applied for in either public or private property.

10.3 Choice set generation

Knowing the search preferences of households, it is possible to construct choice sets for each individual taking into account their preferences. This section continues with an outline of the choice set generation methodology, followed by the available data sources and concludes with the results of the choice set generation process.

10.3.1 Methodology

The following criteria and constraints were included in the choice set generation process:

- *Temporal supply constraints*: Temporal supply constraints increase or reduce the time a dwelling on the market. In this case, a deterministic approach was followed: the availability of all dwellings was increased or decreased simultaneously in monthly intervals, varying from one month to 12 months. In the analysis presented in this section a default value of 3 months has been used.

- *Temporal demand constraints*: Temporal demand constraints decrease or increase the time a household is on the market for a new dwelling. This period was increased in monthly intervals, varying from one month to 12 months. In the analysis presented in this section a default value of 3 months has been used. The usage of the time of the market of the respondent has been evaluated.

- *Affordability constraints*: Affordability constraints indicate the lower and upper bound of the price of a new dwelling. This constraint can be directly given by the respondent, but can also be based on affordability or purchasing power. No upper or lower limit on the dwelling price is used in the default case.

- *Locational constraints*: Locational constraints reduce the spatial extent of the search area. It is possible to impose deterministic constraints or model stochastic constraints based on distance to work, distance to school or distance to parents. By default, no constraints have been imposed on the dwelling. However, the preferred locations
by the respondent have been evaluated in the choice set generation process.

- **Market segment constraints**: Market segments constraints include constraints limiting the access to market segments (e.g. HDB New sale, HDB resale, private) due to regulation or preferences.

- **Dwelling constraints**: Dwelling constraints limit the type of dwelling as well as the size and number of rooms a dwelling has. By default, no constraints have been imposed on the dwelling. However, dwelling constraints mentioned by the respondent have been evaluated in the choice set generation process.

Figure 10.11 highlights this choice set generation process. Inputs in the choice set generation process are shown on the right hand side. These inputs include the decision-makers, a series of alternatives (to be presented in the next section) and spatial information. The set of alternatives is considered to be the universal choice set. Subsequently, a series of criteria is applied to the universal choice set. These include the temporal criteria, criteria concerning the market segments, spatial constraints, dwelling size constraints and affordability constraints. These constraints can either be based on statistical models, or can be deterministic constraints based on the responses of the decision-maker. These constraints combined result in a set of feasible alternatives. While this is depicted as a sequential process, the steps can be performed in any order. Dependent on the number of feasible alternatives, it might be necessary to sample from this set, either by random sampling or weighted sampling. As a final step, the feasible alternatives are enriched with attributes that are dependent on the decision-maker socio-demographic characteristics.

### 10.3.2 Data

**Transaction data**

HDB projects constructed under the build-to-order (BTO) scheme and the Design, Build and Sell Scheme (DBSS) were obtained compiled from two sources ([Tealida, 2016](#); [Wikipedia, 2016](#)). HDB BTO and DBSS projects typically consist of several blocks, and several types of units with a different number of rooms and sizes. The blocks belonging to each HDB BTO and DBSS project were obtained by searching for the accompanying blocks by project name on the Singaporean website StreetDirectory. Missing details,
Figure 10.11: Choice set generation process
such as prices and number of units for some HDB projects were gathered from the official HDB website and enriched with data found on several blogs documenting the Singapore property market. In total 249 HDB BTO and DBSS projects were identified, consisting of 2507 blocks. This resulted in a comprehensive dataset on all HDB BTO blocks in Singapore. To my knowledge, this is first dataset which provides an overview of HDB BTO’s released since 2000 and completed until 2018.

Housing Development Board Resale transactions were obtained from the open data portal of Singapore government (HDB, 2016a). Transaction data was available at the unit-level. from January 1, 2000 until May 31, 2016. For each transaction, the block number, street name, storey range, flat model, floor area, transaction month, lease commence date and resale price is given. All transactions were geo-coded based on the block number and street name provided.

Private market data transactions were downloaded from URA’s Real Estate Information System (REALIS) (URA, 2016). REALIS contains property transactions at the unit-level. Fields stored in REALIS include the property name, property address, unit number, floor level, floor area and tenure. Furthermore, it is mentioned whether a property was transacted as new sale, sub sale or resale and whether the purchaser resided in an HDB flat.

Matching recent moves to transactions
Whereas in the previous analysis use of was made of the dwelling type a household stated to have moved to, in the ensuing a higher level of detail is required. Therefore, the stated moves by survey respondents are matched to the transactions collected (previous section). As a starting point the stated dwelling type of a respondent was taken: respondents stated to have moved to HDB New sale were only matched to HDB BTO & DBSS blocks etc.. Subsequently the following process was executed:

- **HDB New sale**: Households who stated to have moved to an HDB New sale flats were matched with HDB New sale BTO and DBSS projects. The match was made based on the respondent’s postal code and stated flat type. Where the compilation of the BTO’s proved to be the most difficult, the matching of stated transaction to

- **HDB resale**: Households who stated to have purchased an HDB resale flat were matched with HDB resale transactions. The match was based on the respondent’s postal code, postal code, floor area,
Chapter 10. Residential search in Singapore

flat type and price. The approval date of the HDB resale transaction was compared with the year that the household moved house.

- **Private sale:** Households who have stated to have purchased a dwelling from the private market were matched with private sale transactions. The match was based on the respondent’s and transaction’s postal code, the transaction price, the floor area, property type. The contract date of the registration was compared with the year that the household moved house.

A summary of the percentage of matched transactions is reported in Table 10.1; Figure D.4, Figure D.5, Figure D.6 and Figure D.7 provide more detail on the matching.

Only 65% of the households who stated to have moved to HDB new sale dwellings could be matched HDB BTO and DBSS projects, despite the number of criteria being limited. Over 50 respondents who could not be matched were residing in HDB blocks constructed before the year 2000; prior to the start of the HDB BTO scheme. It is hypothesized that these respondents might have purchased an HDB flat, but do not know their future postal code or misinterpreted the question asking for their current address details. Less than 5 households were found to have moved to HDB Sales-of-Balance flats. Exact details of these dwellings, such as year on market, address and number of units, was not available in public data sources.

Nearly 88% of households who stated to have moved to HDB resale flats were matched to HDB resale transactions; nearly 75% of households who have moved to private property could be matched to transaction.

<table>
<thead>
<tr>
<th>Dwelling type</th>
<th>Number of observations</th>
<th>Matched to transactions</th>
<th>Match percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDB New sale</td>
<td>310</td>
<td>202</td>
<td>65.2</td>
</tr>
<tr>
<td>HDB Resale</td>
<td>265</td>
<td>233</td>
<td>87.9</td>
</tr>
<tr>
<td>Private property</td>
<td>230</td>
<td>172</td>
<td>74.8</td>
</tr>
<tr>
<td>Total</td>
<td>805</td>
<td>607</td>
<td></td>
</tr>
</tbody>
</table>

In line with the choice set generation and formation framework presented in the residential literature review alternatives were selected from the universal choice set. This universal choice set is assumed to contain all
available alternatives on the residential market during the time a respondent was active on the market.

10.3.3 Results

To evaluate the influence of the choice set generation process on the choice set size, as well as the average level price level in the choice set and the effect on a set of distance distributions in the choice set generation process the constraints have been applied piece-wise to the choice set generation process.

A procedure has been written that selects alternatives based on all units in the transaction database. This selection can be limited based on the aforementioned constraints. This procedure has been written in Java and results in a statistics file, a Biogeme model file and a Biogeme data file. For the HDB BTO and DBSS the number of units per type (Studio, 1-Room, 2-Room, etc) have been considered as individual alternatives.

A visual example of the output is presented in Figure 10.12. The figure shows an example of choice sets generated for a household choosing to live in HDB resale; only 3,000 randomly sampled HDB resale alternatives are shown. If no criteria are applied to the choice set generation, alternatives are present in all HDB towns. A clear shift can be observed in the distribution of the alternatives over the island; there are only few alternatives available at the southern side of the island (Queenstown, Gmih Moh), which is located closer to the Central Business District. In this case, the respondent has indicated to only consider one area for HDB resale. By introducing a spatial criterion, all sampled alternatives are located at the eastern end of the island.

Choice set size

In this section the effects of applying different criteria on the choice set size are presented. Figure 10.13 shows the number of average number of alternative in the choice set per chosen dwelling type; a breakdown is given by the number of alternatives per market.

In all cases, a dwelling is assumed to be on the market for three months; a household is assumed to be active in the three months prior to the purchase date. By not including any constraints other than the availability of the dwelling, and the presence of the household on the market, the choice set of respondents choosing HDB new sale consists of approximately 25,000
HDB new sale units, 12,000 HDB resale units and 13,000 private units. The number of alternatives of respondents opting for a dwelling on the HDB resale market as well as the private market are in the same order magnitude, albeit a bit smaller. Introducing a price criterion further limits the number of alternatives, most notably of alternatives in HDB resale and the private market; introducing dwelling size criteria reduces the size of the choice sets. The size of the choice set is most influenced by limiting the number of areas based on the household’s preferences; especially for households opting for HDB new sale, the number of private alternatives becomes very low, indicating a low availability of private dwellings in the areas that these respondents preferred. Introducing temporal criteria based on the households’ search time decreases the size of the choice set even further.

A similar analysis can be performed by decreasing or increasing the time a household or a dwelling is on the market. For instance if households are
active on the market for 12 months, and dwellings remain unsold for 12 months, the amount of private dwellings in the universal choice set would increase to 70,000 units.

**Price of alternatives**

Figure 10.14 shows the effect of different criteria on the average price of the alternatives in a household’s choice set; no sampling was performed to obtain these values. One of the underlying hypothesis to this analysis is that by introducing constraints, the average price in the choice set would move towards the chosen price.

The average price of all dwellings in the choice set for households choosing HDB new sale will hover around S$700,000. By introducing the search time of a household the average price does not change much. A different trend can be observed when introducing dwelling size criteria; the average price drops. If only alternatives are included in the choice set in markets that the household considered, the average price of the choice set drops. For households choosing a more expensive dwelling, the average price of alternatives in the choice set approximately equals the price of the chosen dwelling. By reducing the spatial extent to the areas that a household considered, the average price in the choice set drops for
households choosing lower priced dwellings; for higher priced dwellings this is less the case. If all constraints were to be introduced simultaneously, the average price of the choice set drops further. This analysis indicates that, if other criteria are met, a household might not choose the least expensive alternative in a choice set, and that price parameter estimates might be positive.

The average price of all dwellings in the choice set for households choosing HDB resale will hover around S$700,000; as no criteria are introduced, this is similar for respondents choosing HDB New sale and private property. By introducing criteria on the search time, the average of price of all alternatives is slightly higher. When dwelling size are criteria introduced, the average price of alternatives in the choice set decreases. By introducing the criteria households have for markets and areas, the price decreases further. However, in both cases this effect is not as pronounced as when is the case for HDB New sale.

In the case of respondents opting for private property, an opposite trend can be observed. By introducing constraints on the dwelling size, the average price in the choice set drops slightly. By introducing constraints on the considered areas, the average price drops further, especially for households choosing a dwelling between S$800,000 and S$1,000,000. When only the considered markets are introduced in the choice set generation process, the average price increases, in line with expectations: respondents opting for private sale mainly considered dwellings on the private market.

**Distance to anchor points**

In this section the distances of the alternatives in the choice set to anchor points are compared to the distance distributions as observed for the chosen alternatives. The underlying hypothesis is that respondents consider alternatives, either based on price, size or market that minimize distances to anchor points.

Figure 10.15 shows the average distance of all employed household members to their work location. The line shows the distribution as observed in the chosen alternatives. Bars show the distance distributions per market in the choice set. Households opting for HDB New sale, on average, reside further from their job locations. However, there are also no residential alternatives in their choice set close to their job locations. Households opting for HDB resale dwellings and households opting for private dwellings had dwellings available when spatial criteria are applied to the choice set.
10.3. Choice set generation

Figure 10.14: Chosen price versus average price in choice set with applying different search criteria

![Graph showing chosen price versus average price in choice set with applying different search criteria.](image)

**Constraints**
- No constraints
- Price constraints
- Dwelling size
- Considered markets
- Considered areas
- Search time
- All constraints
Figure 10.15: Chosen distance distribution to employment location versus availability in choice set

generation process.
10.4 Discussion & outlook

This chapter has set out to provide insight in households’ residential search criteria based on revealed preference data and subsequently applied these criteria in the choice set generation process, and evaluated the outcome on choice set size, average price of dwellings in the choice set and the distance to work. To generate choice sets on the level of the individual dwelling, household’s stated move was matched to actual transactions found in a compiled transaction database.

Households opting for either HDB or private rental dwellings spent up to two months searching for a dwelling; households choosing for HDB resale for the second time, or for a private dwelling spent up to six months searching for a dwelling, which can indicate their is no high urgency for a new dwelling. Households opting for an HDB resale flat for the first time spent on average four months on the residential market. Households opting for HDB new sale search on average for six months; it should be kept in mind that HDB releases occur approximately four times per year. The number of empirical studies investigating search duration are limited. Baryla and Zumpano (1995) investigate how real estates agents influence search time and conclude that the usage real estate agents leads to a lower search time. First-time home buyers, as well as out-of-town home buyers tend to search longer than more experienced buyers. They mention an average search duration of 12 weeks. Anglin (1997) finds that market familiarity, the quality of information and buying experience reduce the average search time of four months. Chernobai and Hossain (2012) show that buyers who intend to stay longer at their prospective dwelling search for a longer span of time; they found that households search for more than six months before they find a suitable dwelling. The results found for Singapore are in the same order of magnitude, with the exception that second-time home buyers tend to search longer in Singapore, despite the fact that they can be considered experienced buyers.

To a large extent the size of the universal choice set is influenced by this temporal dimension of the search process. Households opting for HDB resale would have 14,000 HDB resale alternatives in their choice set and 15,000 private dwellings if their search time is taken into account. However, if households are assumed to be active on the market for only three months, and household’s other criteria are being accounted for the number
of alternatives in the universal choice set drops to less than 1,000 dwellings. This decrease in the number of attributes can be mainly attributed to the limited spatial extent that households consider when searching for a new dwelling; this is most limiting criterion in choice set size.

Still, households state to have visited up to five properties and seriously consider three properties. The fact that households only consider a limited amount of properties is in line with empirical evidence. Barrett (1976) found that households inspected up to five houses in Toronto; Huff (1986) found that households saw 15 vacancies located in a small number of areas.

The large price differences between the HDB new sale, HDB resale and the private property market, and also within the private property market, highlight that affordability is probably a driving factor in residential location choice. However, if all search criteria are accounted for, the average price of alternatives in the choice set is higher than when solely the price criteria are applied, indicating the trade-off between size, location, preferred market segments and price.

The difficulty of exactly matching property transaction to stated moves in the residential survey again highlight the difficulties of obtaining exact answers in an (online) survey. Theoretically, it is possible to have respondents select their transaction from a set of transactions. Whether respondents would be open to being faced in an (online) survey with such data remains open for future research.

The next chapter will conclude the investigation of residential mobility and residential location choice in Singapore and will evaluate the impacts of using different choice sets in residential location choice models for Singapore. Chapter 12 will provide an overall synthesis of the findings presented in this thesis.
Chapter 11

Residential location choice in Singapore

11.1 Introduction

Once a decision to move is made and one or more vacancies are considered to be relevant residential alternatives, the individuals or households requirements must be explicit to evaluate the alternative(s) in the set of feasible alternatives. Often residential location choice studies consider the zone as level of analysis (e.g. Chen et al., 2008; Weisbrod et al., 1980). A series of studies has analyzed the neighbourhood (Guo and Bhat, 2007), the parcel (Srour et al., 2002), the building (Lee et al., 2010; Lee and Waddell, 2010) or the dwelling unit (Habib and Miller, 2009; Belart, 2011; Schirmer et al., 2013). Whereas previous research has either sampled alternatives from the universal choice set (e.g. Lee and Waddell, 2010) has considered a constrained choice set based on observed commute time (Zolfaghari et al., 2012; Rashidí and Mohammadian, 2015), in this chapter alternatives are selected based on actual search constraints.

In the previous chapter the focus was on choice set formation and generation; this chapter continues with the estimation of residential location choice models. These models are estimated on the level of the individual dwelling unit and are presented in section 11.3. Prior to presenting the estimated models, a descriptive analysis is presented in section 11.2. While this descriptive analysis follows the cross-section of respondents of the previous chapter by chosen dwelling type and tenure, the residential choice models presented in this chapter are only estimated for households moving to HDB resale, and alternatives are only selected from the pool of HDB
resale transactions. Section 11.4 concludes this chapter with a discussion of model results.

11.2 Descriptive analysis

Dwelling type transitions
The first analysis is the analysis of the transition between dwelling types. Figure 11.1 shows this transition between dwelling types. A breakdown is given by the current dwelling / tenure / purchase frequency. Households moving to an HDB New sale for the first time mainly move to HDB 4-Room flats (54%), and most respondents remain in the same dwelling type: HDB 4-Room. Households purchasing HDB new sale for the second time either remain in the same dwelling type (HDB 4-Room, 22.7%), or move up from HDB 3-Room flats (10.6%). Over 16% of the households purchasing an HDB 4-Room flat move up from an HDB 3-Room flat, whereas most households purchasing an HDB resale flat for the second time move from an HDB 4-Room to an HDB 5-Room flat. Households residing in HDB Rental mainly remain in 3-Room flats, but make the transition from HDB 3-Room to HDB 4-Room in 13% of the cases. Households moving to private housing mainly come from private housing, followed by respondents stemming from HDB 5-Room and HDB 4-Room flats. The transition from private property to HDB dwelling seems to be fairly constant. Approximately 5% of the respondents moving transition private property to HDB 4-Room or HDB 5-Room flats.

Distance to employment & education
The distance to the employment of the respondent and their household members is presented in Figure E.2. Respondents residing in rental properties, both HDB and private, live closer to their employment location as respondents living in other dwelling types.

Social contacts
As outlined in the literature review in Chapter 7, proximity to social contacts is an important factor in the choice for a new dwelling. Upon being asked about the five people respondents see most outside of your household for non-work purposes, respondents highlighted that they met friends / acquaintances most (>60%), followed by colleagues (10%). Family relationships were asked on a very detailed level (e.g. brother / sister,
Figure 11.1: Transition in dwelling type

<table>
<thead>
<tr>
<th>Current dwelling type</th>
<th>Previous dwelling type</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HDB New sale – First-timer</strong></td>
<td>HDB Studio, 1 &amp; 2–Room</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>HDB 3–Room</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>HDB 4–Room</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>HDB 5–Room &amp; above</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Private</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>HDB New sale – Second-timer</strong></td>
<td>HDB Studio, 1 &amp; 2–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 3–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 4–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 5–Room &amp; above</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Private</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>HDB Resale – First-timer</strong></td>
<td>HDB Studio, 1 &amp; 2–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 3–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 4–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 5–Room &amp; above</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Private</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>HDB Resale – Second time or more</strong></td>
<td>HDB Studio, 1 &amp; 2–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
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<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 4–Room</td>
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</tr>
<tr>
<td></td>
<td>HDB 5–Room &amp; above</td>
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<td></td>
<td>Private</td>
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<tr>
<td><strong>HDB – Rental</strong></td>
<td>HDB Studio, 1 &amp; 2–Room</td>
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<td>HDB 3–Room</td>
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</tr>
<tr>
<td></td>
<td>HDB 4–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 5–Room &amp; above</td>
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<td></td>
<td>Private</td>
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<tr>
<td><strong>Private – Sale</strong></td>
<td>HDB Studio, 1 &amp; 2–Room</td>
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<td>HDB 3–Room</td>
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<tr>
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<td>HDB 4–Room</td>
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</tr>
<tr>
<td></td>
<td>HDB 5–Room &amp; above</td>
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</tr>
<tr>
<td></td>
<td>Private</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Private – Rental</strong></td>
<td>HDB Studio, 1 &amp; 2–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 3–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 4–Room</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>HDB 5–Room &amp; above</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Private</td>
<td>0.7</td>
</tr>
</tbody>
</table>
brother-in-law, great grandchild); if all family relationships would be aggregated, family would comprise of 20% of the total.

For each of these 5 contacts, respondents were asked in which area and sub-zones they met for the last time. An aggregated overview of responses is provided in Figure 11.2: Densely populated residential areas around the central area, the East Coast (Bedok, Eunos) and the Western area (Jurong) are mentioned often. However, what also becomes apparent is that respondents mention the downtown area, and more specifically Orchard Road and the Downtown Core as areas where they last met their social contacts.

A similar question enquiring for frequent meeting locations provided additional insight in important areas for social contacts. Judging by the results in Figure 11.3: a similar image appears; however the Orchard Area is mentioned most often, as compared to other areas. On average respondents mentioned 1.5 areas where they meet their closest friends.
11.3 Specification & results

11.3.1 Model specification

Table 11.1 and Table 11.2 summarize the variables that have been considered in the different choice models that are presented in this chapter. A distinction has been made between variables describing the dwelling, variables describing the block (the apartment block in which the dwelling is located), variables describing the block’s surroundings, variables describing the household’s spatial relationships, such as the distance to employment as well as the distance to the social network and variables describing the neighbourhood’s accessibility.

Model variables have been entered in a step-wise fashion to a constant only model. Variables representing discrete variables, have been entered as a continuous variables and as discrete variables representing groups. All model estimations have been performed with Biogeme (Bierlaire, 2003); models have been specified as multinomial logit (MNL) models with the dwelling a respondent moved to as the chosen alternative and alternatives available on the market prior to the transaction date as alternatives present...
in the universal choice set; subsequently, the choice set generation process presented in Chapter 10 has been applied. The MNL model is the most commonly applied model in residential location choice studies and has shown to yield consistent parameter estimates when estimated on a subset of alternatives. In this case, a subset of maximum 1,000 alternatives is used, as this provided tractable computation times and thus allowed for experimenting with a range of model specifications.

In the remainder of this chapter only respondents opting for HDB Resale dwellings have been considered and only HDB Resale alternatives have been included in the choice set generation process. This has been done for the following reasons:

- The descriptive analysis in Chapter 10 has shown that households opting for an HDB resale flat consider either solely either HDB resale, or HDB resale and HDB new sale, or HDB resale and private dwellings. The workings of the HDB new sale differ from the HDB resale and private market.
- The residential mobility model presented in Chapter 9 clearly showed which households choose to move to HDB new sale and private properties, but did not reveal a clear profile of movers to HDB resale. Models for respondents moving to HDB resale have the potential to reveal which attributes are considered attractive for households removing to HDB resale.
- The majority of the areas developed are greenfield sites, with no amenities or transport network in place. Evaluating the effect of destination diversity or accessibility to employment on residential location choice would solely be based on the expectations of households opting for HDB new sale and not on data available to the analyst.

For each decision-maker a series of choice sets is generated based on their actual search preferences; the effect of these choice sets on parameter estimates is evaluated. These different choice sets and the expected model outcomes are presented in Table 11.3.

11.3.2 Results

In this section the results of the base model and the results of models using preference constrained choice sets are summarized. A more elaborate
<table>
<thead>
<tr>
<th>Variable</th>
<th>Explanation</th>
<th>Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dwelling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transaction price</td>
<td>The transaction price of the dwelling as listed in the data source [100,000 SGD]</td>
<td>Negative</td>
</tr>
<tr>
<td>Price per psm</td>
<td>Price per square meter (psm), dwelling size is given</td>
<td>Negative</td>
</tr>
<tr>
<td>Price household yearly income ratio</td>
<td>Price per square meter, dwelling size is given</td>
<td>Negative</td>
</tr>
<tr>
<td>Dwelling size</td>
<td>Size of the dwelling in square meters</td>
<td>Positive</td>
</tr>
<tr>
<td>Number of rooms</td>
<td>Number of rooms as given by the household</td>
<td>Positive</td>
</tr>
<tr>
<td>Rooms per person</td>
<td>Number of rooms as given by HDB divided by number of persons in household</td>
<td>Negative</td>
</tr>
<tr>
<td>Square meter per room</td>
<td>Square meter per room</td>
<td>Positive</td>
</tr>
<tr>
<td>Floor level</td>
<td>Floor level, provided as range</td>
<td></td>
</tr>
<tr>
<td><strong>Block</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion year</td>
<td>Construction year of dwelling, entered as number of years on remaining on lease at time of purchase</td>
<td>Negative</td>
</tr>
<tr>
<td><strong>Spatial - block</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to MRT</td>
<td>Euclidean distance to train station, entered as both continuous variable and step-wise, with and without vehicle</td>
<td>Negative</td>
</tr>
<tr>
<td>Highway within 50 meters</td>
<td>Distance to highway, only considered when it is unobstructed</td>
<td>Negative</td>
</tr>
<tr>
<td>Above grade metro within 50 meters</td>
<td>Above grade railtrack withing 50 meters of dwelling, only when unobstructed</td>
<td>Negative</td>
</tr>
<tr>
<td>Distance to primary school</td>
<td>Primary school within 1 km, euclidean distance, and between 1 km and 2 km</td>
<td>Positive</td>
</tr>
<tr>
<td>Distance to top primary school</td>
<td>Top primary school</td>
<td>Positive</td>
</tr>
<tr>
<td>Greenery</td>
<td>Percentage park within 300 meters</td>
<td>Positive</td>
</tr>
<tr>
<td>Building density</td>
<td>Percentage built-up within 200 meters</td>
<td>Negative</td>
</tr>
<tr>
<td>Diversity</td>
<td>Diversity of amenities within 300 meters</td>
<td>Positive</td>
</tr>
<tr>
<td>Walk indices</td>
<td>Walk indices to daily needs, stores, parks, healthcare</td>
<td>Positive</td>
</tr>
</tbody>
</table>
Table 11.2: Variables considered in residential location choice models (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Explanation</th>
<th>Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial - social</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to employment</td>
<td>Euclidean distance to parents for respondents having lived in Singapore previously and not living with parents</td>
<td>Negative</td>
</tr>
<tr>
<td>Distance to parents</td>
<td>Average euclidean distance to the subzones where respondents and household members are employed</td>
<td>Negative</td>
</tr>
<tr>
<td>Distance to household employment</td>
<td>Average euclidean distance to the subzones where respondents meet their 5 closest contacts</td>
<td>Negative</td>
</tr>
<tr>
<td>Distance to social contacts, meeting</td>
<td>Average euclidean distance to the subzones where the 5 closest contacts live</td>
<td>Negative</td>
</tr>
<tr>
<td>Distance to social contacts, living</td>
<td>Average euclidean distance to the subzones where they meet with the 5 closest contacts</td>
<td>Negative</td>
</tr>
<tr>
<td><strong>Accessibility</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT employment accessibility</td>
<td>Number of jobs accessible in 40 minutes by public transport</td>
<td>Positive</td>
</tr>
<tr>
<td>Private accessibility employment</td>
<td>Number of jobs accessible in 30 minutes by private vehicle</td>
<td>Positive</td>
</tr>
<tr>
<td>PT accessibility to commercial GFA</td>
<td>Commercial gross floor area accessible within 20 minutes by public transport</td>
<td>Positive</td>
</tr>
<tr>
<td>PT accessibility to sports &amp; park</td>
<td>Sports and parks accessible within 20 minutes by public transport</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Discussion of the results is presented in section 11.4.

**Base model**

Table 11.4 reports three base models estimated for this study: (1) a base model, without spatial variables, (2) a model containing spatial variables describing the block, and (3) a model containing variables describing the dwelling, block, and spatial variables dependent on the household. In all cases, 1,000 alternatives have been sampled from dwelling being transacted on the HDB resale market in the three months prior to the transaction date of the purchased dwelling.

In line with expectations, it is found that households prefer a larger dwelling. On average, households prefer more smaller rooms than fewer
Table 11.3: Choice set constraints: hypotheses on model outcomes

<table>
<thead>
<tr>
<th>Choice set constraints</th>
<th>Hypotheses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size constraints</td>
<td>Dwelling size related variables will drop in significance as dwellings that are not desired are filtered out of the choice set.</td>
</tr>
<tr>
<td>Price constraints</td>
<td>Price related attributes might switch to positive as unaffordable alternatives are filtered out of the choice set.</td>
</tr>
<tr>
<td>Spatial constraints</td>
<td>Spatial variables describing the location of a dwelling relative to anchor points will drop in significance. The increased number of alternatives in the preferred area can result in significant variables describing the immediate environment of the block, including destination diversity, but also variables capturing negative externalities such as noise and emissions.</td>
</tr>
<tr>
<td>Size, price, spatial constraints</td>
<td>Spatial variables describing the location of a dwelling relative to anchor points will drop in significance. In addition to the expected significance of variables describing the direct environment of the block, it is expected that variables describing the dwelling unit, such as floor level, will be more significant.</td>
</tr>
</tbody>
</table>

large rooms. Contrary to expectation, households prefer a higher price per square meter. The negative parameter for the number of rooms per person households prefer not to have an excess of rooms. This parameter differs for households with and without children; households without children mind an excess of rooms less, which can indicate that a family expansion is still expected. No preference for floor level could be found.

Including variables describing the block in which a dwelling is located improved model performance slightly judging by the adjusted rho square. Of the spatial variables reported in Table 11.1 blocks located within one kilometre (Euclidean) distance proved to have a significant and positive influence on the choice for a dwelling. This preference was similar for households with and without children.

Including variables describing the relationship of the household to the locations improves model performance greatly. In the final specification, these variables include the average crow-fly distance to employment, the distance to the respondent’s parents and the average crow-fly distance to the location where respondents last met their social contacts. In this model specification, the negative parameter for the price per square meter indicates
Table 11.4: Residential location choice: base models (1,000 randomly sampled alternatives)

<table>
<thead>
<tr>
<th></th>
<th>Base model Estimate (t-test)</th>
<th>Spatial - Block Estimate (t-test)</th>
<th>Spatial - Block and social Estimate (t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dwelling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size [sqm]</td>
<td>0.0418 (5.01)</td>
<td>0.0433 (5.1)</td>
<td>0.0444 (5.01)</td>
</tr>
<tr>
<td>Size per room [sqm / room]</td>
<td>-0.109 (-2.36)</td>
<td>-0.121 (-2.55)</td>
<td>-0.123 (-2.45)</td>
</tr>
<tr>
<td>Price psm [log]</td>
<td>1.39 (3.32)</td>
<td>1.27 (2.97)</td>
<td>-1.3 (-2.33)</td>
</tr>
<tr>
<td>Price hh income ratio</td>
<td>-0.156 (-4.01)</td>
<td>-0.158 (-4.02)</td>
<td>-0.175 (-3.95)</td>
</tr>
<tr>
<td>Room per person, no children</td>
<td>-1.53 (-4.08)</td>
<td>-1.53 (-4.04)</td>
<td>-1.48 (-3.74)</td>
</tr>
<tr>
<td>Room per person, children</td>
<td>-1.72 (-2.41)</td>
<td>-1.72 (-2.4)</td>
<td>-1.77 (-2.33)</td>
</tr>
<tr>
<td>Floor level between 1 and 6</td>
<td>-</td>
<td>-</td>
<td>-1.3 (-1.7)</td>
</tr>
<tr>
<td><strong>Block</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between 10 and 20 years old</td>
<td>-</td>
<td>-</td>
<td>0.403 (2.4)</td>
</tr>
<tr>
<td><strong>Spatial - block</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRT Station within 400m</td>
<td>-</td>
<td>-</td>
<td>0.421 (2.31)</td>
</tr>
<tr>
<td>Top primary school within 1000m</td>
<td>0.264 (2.27)</td>
<td></td>
<td>0.283 (2.22)</td>
</tr>
<tr>
<td><strong>Spatial - social</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to employment [avg, km]</td>
<td>-</td>
<td></td>
<td>-0.136 (-4.76)</td>
</tr>
<tr>
<td>Distance to parents [km]</td>
<td>-0.144 (-4.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to social contacts, meeting [km]</td>
<td>-0.287 (-7.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Statistics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of decision-makers</td>
<td>229</td>
<td>229</td>
<td>229</td>
</tr>
<tr>
<td>Max number of alternatives</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Rho-square</td>
<td>0.009</td>
<td>0.010</td>
<td>0.122</td>
</tr>
</tbody>
</table>
that households do not prefer dwelling with higher price per square meter. Furthermore, households do not prefer dwellings located on a lower floor level and prefer blocks that were between the 10 and 20 years old at the time of moving. A MRT station within 400 meters is preferred by households that own and do not own a vehicle. The negative parameter estimate for the distance to employment indicates that households attempt to live close to their workplace. A similar trend can be seen for the preference for the proximity to parents: respondents prefer close to their parents. Finally, respondents prefer to live close to places where they meet their 5 closest social contacts. Other spatial variables reported in Table 11.1 such as accessibility by public transport proved not have a significant influence on residential location choice. Including the distance to current primary school of a household did improve model performance, but has been excluded from the model specification: due to educational policies, it is highly likely that children will go to a school in proximity to their dwelling.

Preference constrained choice sets

Table 11.5 reports the results when different choice sets, based on household’s stated search preferences, are used in the model estimations. The considered search preferences include the considered dwelling size of a dwelling, the considered price range, the considered areas and a combination of the considered dwelling size, price range and considered areas.

Incorporating size preferences in the choice set formation process does not have a significant impact on model results, as compared to a model considering the universal choice set. All parameters have the same sign and order of magnitude; floor level being the only variable that yields an insignificant parameter estimate.

When including only dwellings in the preferred price range changes can be observed in the model estimation. A higher price per square meter is perceived positive instead of carrying the expected negative sign. The parameter estimated of the ratio between dwelling price and household income is not significant and no differentiation could be between the preference for the number of rooms per person for households with and without children. Judging by the rho-square, a choice set including only dwellings within the preferred price range, provides the highest explanation power.

Reducing the search space of households to the areas that household’s indicate a preference for model results in several changes. The estimated
### Table 11.5: Residential location choice models: Preference constrained choice sets

<table>
<thead>
<tr>
<th></th>
<th>Size constrained</th>
<th>Price constrained</th>
<th>Spatially constrained</th>
<th>Size, space, price constrained, 9 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate (t-test)</td>
<td>Estimate (t-test)</td>
<td>Estimate (t-test)</td>
<td>Estimate (t-test)</td>
</tr>
<tr>
<td><strong>Dwelling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size [sqm]</td>
<td>0.045 (5.09)</td>
<td>0.0815 (7.65)</td>
<td>0.0486 (4.81)</td>
<td>0.102 (2.03)</td>
</tr>
<tr>
<td>Size per room [sqm/room]</td>
<td>-0.126 (-2.57)</td>
<td>-0.096 (-1.74)</td>
<td>-0.16 (-2.79)</td>
<td>-0.154 (-2.68)</td>
</tr>
<tr>
<td>Price psm [log]</td>
<td>-1.11 (-2.04)</td>
<td>3.1 (4.39)</td>
<td>-</td>
<td>4.57 (5.42)</td>
</tr>
<tr>
<td>Price hh income ratio</td>
<td>-0.164 (-3.7)</td>
<td>-0.922 (-1.89)</td>
<td>-0.155 (-3.42)</td>
<td>-</td>
</tr>
<tr>
<td>Room per person</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room per person, no children</td>
<td>-1.56 (-3.91)</td>
<td>-1.71 (-3.6)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Room per person, children</td>
<td>-1.9 (-2.49)</td>
<td>-2.18 (-2.4)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Floor level between 1 and 6</td>
<td>-</td>
<td>-0.252 (-1.83)</td>
<td>-</td>
<td>-0.214 (-1.54)</td>
</tr>
<tr>
<td>Between 10 and 20 years old</td>
<td>0.423 (2.52)</td>
<td>0.479 (2.7)</td>
<td>0.292 (1.57)</td>
<td>0.487 (2.69)</td>
</tr>
<tr>
<td><strong>Spatial - block</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRT Station within 400m</td>
<td>0.393 (2.18)</td>
<td>0.406 (2.2)</td>
<td>0.277 (1.59)</td>
<td>0.387 (2.03)</td>
</tr>
<tr>
<td>Top primary school within 1000m</td>
<td>0.262 (2.05)</td>
<td>0.279 (2.2)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Spatial - social</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dist to employment [avg, km]</td>
<td>-0.134 (-6.21)</td>
<td>-0.138 (-4.82)</td>
<td>-0.0784 (-2.13)</td>
<td>-</td>
</tr>
<tr>
<td>Dist to parents [km]</td>
<td>-0.143 (-4.24)</td>
<td>-0.146 (-4.28)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dist to social contacts, meeting [km]</td>
<td>-0.282 (-7.76)</td>
<td>-0.289 (-8.02)</td>
<td>-</td>
<td>-0.246 (-3.82)</td>
</tr>
<tr>
<td><strong>Statistics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of decision-makers</td>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
</tr>
<tr>
<td>Maximum number of alternatives</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Rho-square</td>
<td>0.121</td>
<td>0.185</td>
<td>0.011</td>
<td>0.106</td>
</tr>
</tbody>
</table>
11.4 Discussion & outlook

This chapter has presented residential location choice models in Singapore and has focused on the choice of Housing Development Board (HDB) resale flats based on actual housing decisions. When modelling the choice of a dwelling unit based on revealed preference the analyst is faced with the challenge of determining the choice set available to the researcher; the pool of alternatives in spatial location choice models is generally too large to directly include in model estimations, and additionally, it is unrealistic to assume that the household knows all available alternatives in the market.

Commonly, alternatives are sampled from the universal choice set. In this chapter model results were presented with alternatives sampled from the universal choice set. Additionally, models estimated were presented with choice sets that take into account household’s actual search preferences that include dwelling size, dwelling price and possible areas. Models including spatial variables describing the social environment, combined with choice sets only including alternatives within the preferred price range, perform best judging by the adjusted rho-square.

Estimated parameters carry the expected sign, one exception being the sign for the price per square meter. In a model estimated without constraints, but including spatial parameters, the price per square meter is negative. This is also the case in the model estimated with choice sets that are constrained in dwelling size. Usually, an unexpected parameter estimate occurs when endogeneity is present, i.e., when the independent variable is correlated with the error term due to the omission of dependent variables (Guevara and Ben-Akiva, 2006). In the case for movers to HDB resale flat, relevant variables include the distance to employment, the distance to parents and the distance to the social network. By imposing more constraints on the choice set formation process an insignificant parameter (spatially constrained model) or strongly positive parameter (price and fully constrained) for the
price per square meter is obtained. Zolfaghari et al. (2012) observed a similar effect when the choice set was constrained by commute time. They argue that this initially counter-intuitive result is the result of a screening process in which initially unaffordable dwellings are filtered out of the choice set, and that among the affordable dwellings unobservable quality attributes are present. For Singapore, this screening process by households include most likely the location of parents and the social network.

When constraining the choice set spatially most spatial attributes lose their significance, despite the spatial boundary being a planning area and households opting for HDB resale considering multiple planning up to 4 planning areas. The analysis of the standard distance (chapter 10) revealed that these households only considered dwellings in a spatially limited area.

Households prefer dwellings located in blocks between 10 and 20 years old; no other preference for the age of a block could be observed. A descriptive analysis of resale prices revealed that no significant difference in price for blocks between the 20 and 40 years could be observed (Ng, 2017). Anecdotally, older blocks in Singapore are preferred in Singapore due to the fact that they are more spacious, are located more centrally and have a higher chance of being considered for redevelopment under the selective en-bloc redevelopment scheme (SERS). However, it has to be mentioned that no HDB block in Singapore has lived until the end of its lease and there is no clear government policy on this topic yet. Theoretically, blocks that reach the of their lease will have no value.

Hedonic pricing models for Singapore revealed that prices of HDB dwellings located on higher floors are generally higher than transaction prices of HDB dwelling located on lower floor level. (Lehner, 2011). The model results presented in this chapter show that households do not prefer dwellings located on lower levels when using the price constrained choice set and the fully constrained choice set. However, no clear preference for higher floor levels was observed. An individual who had purchased an HDB dwelling commented in her blog: ‘the premium (... for higher floors ...) is overpriced, and can be used instead for improving the interior’ and ‘A benefit of my low floor is having a garden view. .... It is fun to see the people walking in the garden, .... , children playing hide and seek, .....’. Attributes such as the quality of view were not generated as the collected data does not include the exact floor level and the location of a dwelling inside a block. Additionally, given the limited amount of observed choices it is imaginable...
that there would not be sufficient observations of households considering a dwelling based on such quality attributes.

Models estimated including spatial variables describing a household’s most important locations, expect for the spatially constrained choice set, performed best judging by the rho-square. Indeed, the majority of the households stated to first select a location and then search for a dwelling meeting their criteria. On one hand, it can be argued that household’s adjust their job location and the locations where they meet their social contacts based on the their residential location. Nevertheless, social contacts and the employment location are elements that are likely not to change over longer span of time. These findings are in line with conclusion of previous studies. Zondag and Pieters (2005) concluded households relocate in small area around their previous dwelling; Vyvere et al. (1998) found that households prefer to live close to friends and relatives, as did Belart (2011) for the canton of Zurich. Furthermore, Singapore’s Ministry of National Development found that recently married Singaporeans preferred to live in the same neighbourhood (42%) or the same town (16%) as their parents (Channel News Asia, 2014). The findings of the presented residential location choice model confirm the findings of this survey.

Spatial variables other than variables based on a household’s most important locations were included in model specifications. Of these variables, it was found that a MRT station within 400 meter was preferred. Also, it was found that a top primary school within one kilometre is preferred; households residing within one kilometre have an increased change of being enrolled in a primary school. Hedonic models for Singapore did reveal a price premium for these attributes (Lehner, 2011). Variables describing local accessibility, including destination diversity and other walk indices, were not significant, despite that these could be a proxy for meeting locations with social contacts.

Cascetta et al. (2007) propose to use a dominance variable in the choice set generation process. For Singapore, a dominance variable should include distance to work for each household member, the distance to parents, and to distance to social contacts; this dominance variable can be used for weighted sampling. The relevance of the distance to important spatial anchor points, such as parents, social contacts and employment highlight the necessity to apply an the anchor based sampling approach as proposed by Huff (1986).
Given the fact that these socio-spatial variables greatly improve significance, using solely revealed preference data without socio-demographic attributes for the estimation of residential location choice models will not provide the analyst with valuable results.
Chapter 12

Synthesis & future research

12.1 Synthesis

The forces of the land-use transport feedback cycle, combined with the outcomes of urban and transport planning, influence the transport system as well the distribution of opportunities and subsequently the locations where people, goods, money and ideas meet. The mediating factor between transport and land-use is accessibility. Accessibility is a measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome this spatial separation (Hansen, 1959). A distinction can be made between regional accessibility and local accessibility (e.g. Handy, 1993). Regional accessibility measures the accessibility to jobs or population. Local accessibility describes the accessibility to nearby destinations, and is considered a measure describing the built environment. Other measures describing the built environment include density, diversity, design, and distance to transit (Ewing and Cervero, 2010). Given the relevance of these 5 D’s on travel related decisions, it is necessary to view the built environment as an integral part of the transport land-use feedback cycle.

This brings us to the first objective of this thesis: on one hand there exists the need to describe, measure and design the built environment; on other hand there is the economist’s perspective, that takes interest in what individuals and individuals value when making choices. The second objective is to provide insights in these factors for the city state of Singapore. These insights are contrasted against findings for Switzerland.
Chapter 2 provided an introduction to Singapore. Since its independence, Singapore has developed itself into a First World nation, to large extent due to the active role of the government that has implemented long-term urban plans and a large-scale national housing plan, in which the public housing provider (Huat, 2011). Currently 80% of the Singaporean population resides in public housing provided by the Housing Development Board (HDB), of which 95% is owner-occupied (HDB, 2016b).

Chapter 3 continued with the measurement of accessibility. Leading in the development of Singapore was the 1971 Strategic Concept Plan, which called for a series of high density settlement connected by mass transit to the central business district. Tobler’s first law of geography states everything is related to everything else, but near things are more related than distant things (Tobler, 1970). This deterrence to distance is captured with a distance decay function. Given Singapore’s planned urban environment the question arises whether such a deterrence function measures the imposed spatial structure, individual’s preferences, or both. The chapter provides an overview of the different perspectives that exist on the measurement of accessibility, shows the existing urban structure of Singapore based on public transport smart card data and presents different distance decay functions by trip purpose and mode. A new probability function based accessibility measure is proposed and applied for Switzerland; differences can be observed in accessibility when applying a place-based accessibility measure instead of a constant distance decay function for the whole country.

Chapter 4 looked closer at the measurement of accessibility when realistic walking distances to transit are considered. Given the scarcity of land, in contrast to new towns developed in post-war Europe, the Singaporean residential areas were characterized by expressways, major avenues or other physical barriers (Eng, 1986). This has led to the development of an algorithm to generate a pedestrian network for Singapore, that takes into account crossing opportunities and connections to building. It was shown that using pedestrian network distances, both over road centrelines and an advanced pedestrian network, strongly decreases the accessibility to jobs by foot and public transport.

Chapter 5 researched local accessibility. Accessibility commonly refers to the number of opportunities that can be reached within a certain time. On a local scale however, the diversity of these destinations might matter more. This chapter critically assesses the measurement of diversity and local
accessibility and proposes a new diversity index, that includes the number of desired destinations and does not penalize if there is an abundance of a single destination type, as usually is the case. This measure, and several destination indices, are calculated for both Singapore and the whole of Switzerland using a global points of interest database and network distances to these points of interests. The impact of this measure is assessed by evaluating the choice to walk in both countries by trip purpose. After correcting for socio-demographic characteristics, it is found that the constructed indices best explain home-based and work-based shop trips, but fall short in predicting leisure trips. The diversity of destinations is relevant when measured as the diversity of destinations within 300 meters walking distance; the application of a distance decay function that captures destination up to 15 minutes walking did yield insignificant or counter-intuitive parameter estimates. This indicates that the built environment, in order to support walking as a main mode of transport, should provide a variety of destinations within short distance.

Chapter 6 evaluated the choice to own a vehicle in Singapore and Switzerland. Whereas the choice to walk is considered to be a short-term choice, owning a vehicle is a considered a medium-term choice. For both countries, households with one young child have a lower likelihood of owning one vehicle or purchasing a second vehicle than households with two or more young children or teenagers. As models were estimated on cross-sectional data sets, variables describing household structure cannot be interpreted as key turning points in life to own a vehicle. However, based on retrospective mobility biographies, Beige and Axhausen (2012) find that an increase of household size is a turning point leading to vehicle ownership. A higher diversity of destinations within walking distance decreases the likelihood of owning one or more vehicles. In this case, the diversity of destinations beyond 300 meters, but within 1,000 meters mattered most.

Chapter 7 provided a literature of residential mobility and location choice studies, and combined with chapter 2 laid the foundation for a newly developed residential survey for Singapore, presented in chapter 8. This survey has been conducted with an online panel mainly consisting of Singaporeans and resulted in over 6,000 respondents, of which approximately 1,000 respondents moved house in the period 2012-2015.

Chapter 9 assessed residential mobility in Singapore. Descriptive analysis reveals that 35% of the moves are towards newly built HDB dwellings,
whereas almost 30% of the households opt for a dwelling on the HDB resale market. It is safe to say that, in Singapore, the Housing Development Board is one of the driving forces of urban dynamics. The estimation of a nested logit model reveals a difference with residential mobility in Western countries (e.g. Dieleman, 2001): whereas studies conducted in Europe have shown that mobility rates are high for couples with and without children, in Singapore couples without children tend to move and form a family after moving house. In line with evidence in literature, single person household are most likely to rent a dwelling; owners are less likely to move.

Chapter 10 investigated the residential search process. Descriptive analysis reveals that households search in a limited area and in a limited number of markets. Subsequently, a choice set generation algorithm is proposed that evaluates the number of alternatives available to a household. To a large extent the size of the universal choice set is influenced by this temporal dimension of the search process. However, if households are assumed to be active on the market for only three months, and households’ other criteria are being accounted for, the number of alternatives in the universal choice set drops to fewer than 1,000 dwellings. This decrease in the number of attributes can be mainly attributed to the limited spatial extent that households consider when searching for a new dwelling. Still, households state to only visit up to five properties and seriously consider three properties. The fact that households only consider a limited number of properties is in line with empirical evidence found in literature.

Chapter 11 presented residential location choice models for Singapore. It was chosen to only evaluate decision made by households who opted for HDB resale flats; alternatives were generated from observed HDB resale transactions. In this chapter model results were presented that with alternatives sampled from the universal choice set. Additionally, models estimated were presented with choice sets that take into account households’ actual search preferences that include dwelling size, dwelling price and possible areas. Models including spatial variables describing the social environment, combined with choice sets only including alternatives within the preferred price range, perform best judging by the adjusted rho-square. In this case, the social environment consisted of variable describing a household’s average distance to work, the distance to their parents and the average distance to the locations where they most frequently meet their five closest contacts. Other significant spatial variables included the distance to
a top primary school, as well as the proximity to a mass rapid transit station. Variables such as accessibility to jobs, as the diversity of amenities proved not to be significant.

This leads to the conclusion that diversity and accessibility do matter for both Singapore and Switzerland for short term decisions such as the choice to walk and whether to own a vehicle, or in the case of Switzerland, a second car. However, for long-term decisions, such as the choice for a dwelling, no significant effect could be found: the activity spaces of households proved to be significant in explaining the choice of residence instead of variables describing the immediate built environment. In order to support the usage of active modes this makes it even more relevant to provide for a diverse range of amenities in the immediate environment of residences to curb the use of the motorized transport.

This thesis has not addressed residential self-selection, which can be of relevance when evaluating the choice to walk, the decision to own a vehicle and choice of residence. After all, individuals and households may choose a residential location in line with their travel preferences (e.g. Cao et al., 2009). However, whether this self-selection matters when measuring travel behaviour outcomes of residential location choice is still unclear (e.g. Naess, 2009).

Singapore authorities have embarked on a policy of decentralisation and is starting to develop business districts outside of the Central Business District area, a not uncommon trend in other countries. This is happening on different scales, varying from the development of small to medium-sized business parks to the development of high-density mixed use business districts.

Given the number of moves to newly built public housing, concentrated in purpose-built new towns, and given the fact that these households embark on a new family life, it is necessary to plan residential and commercial development hand-in-hand on the human scale.

12.2 Directions for future research

Short term
Subsequent behavioural research for Singapore has shown that individuals perceive distance differently along different types of side walks: the
presence of shops or shade might decrease the perceived walking time, whereas crossings or walking along a major road (Erath et al., 2016) tend to increase it. For instance, an overhead bridge is perceived as 4 minutes of walking whereas the presence of shade might decrease perceived walking time by 20 percent. Partially, these perceived costs can be incorporated in the pedestrian network generation algorithm. Also, the incorporation of permeable areas, such as parks and public spaces, needs to be evaluated further.

The mode choice models, with the presented local accessibility and diversity indices, revealed not to perform well for home-based leisure trips. On one hand, a further breakdown of leisure activities could provide insight whether certain destination types influence the propensity to walk. On the other hand, not all trips are necessarily correlated with the presence of amenities but are conducive to the presence of other elements enhancing the likelihood to walk. Lee and Moudon (2006) mentions several of these correlates, such as the presence of hills, visually attractive buildings and the presence of sidewalks. Furthermore, given the development of online shopping and a decline in physical retail, an understanding what makes individuals walk beyond shopping is increasingly relevant. Cliffton et al. (2013) propose a composite pedestrian environment index which includes among others, bicycle access, sidewalk density, access to parks, and an amenity index. Such a composite index could further help quantifying the built environment. However, for certain types of leisure activities an even higher level of detail for the pedestrian network might be required, which includes how safe, enjoyable and interesting it is to walk along a given route, and whether it is possible to perform tours meeting these requirements. Whether it is desired to calculate such micro-level indicators for an entire country remains questionable.

Mode choice models have not included regional accessibility variables as these were considered too coarse to describe the immediate environment beyond walking distance. The recent development of software that can calculate accessibility at a high level of spatial detail for both public transport (e.g. Byrd, 2012; Wigginton Conway et al., 2017) and incorporating actual travel speeds by car (Krambeck et al., 2015) open up venues to calculate precise accessibility to opportunities located within one or two transit stops, or within a five minute drive. These accessibilities might compete with accessibility by foot, but are nevertheless of interest. The proposed diversity
indices can also be applied for these meso-accessibility indicators.

There are two main outstanding topics in the residential location choice model. The first concerns the introduction of anchor-based sampling or distance based sampling of the alternatives in the choice set. The second outstanding topic is the incorporation of both HDB New sale and private alternatives in the choice set, given that there are households that consider multiple residential markets. The choice set generation algorithm includes the possibility to do both. Notwithstanding, the question remains whether further sampling methods can help overcome the lack of variables describing the quality of the dwelling.

*Long term*

Several studies have assessed the accuracy of one-day travel surveys. Wolf (2006) reported that the rate of missing trips ranged from 11% to 81%, when comparing the results of computer assisted telephone surveys and GPS data in six household surveys in the US. Forrest and Pearson (2005) found that the number of trips observed in GPS data in their 2002 survey was much higher than the number of trips reported by respondents. Home-based non-work and non-home-based trips suffered most from under-reporting. The usage of other data sources can provide more insight in short trips, such as phone data that can provide insight in mode choice and the role of diversity. However, other data sources than big data can be tapped on. Miller et al. (2015) employs accelerometers and GPS data recorders to conduct a longitudinal study to evaluate whether public transit generates physical activity; such a tailored study can offer more insight in correlates of recreational walking. A similar approach is followed by Tribby et al. (2017) who evaluates self-defined regions and walking activity spaces, and perceived measures of the built environment versus audit data measures of the built environment. Audit data measures have a higher correlation with walking activity spaces, which are generally smaller than self-defined neighbourhoods, than with self-defined regions. Walking activity spaces instead of a network distance band for diversity measures could be applied in further studies in walk choice. For Singapore the usage of GPS data recorders in the CBD was not perceived optimal because of the combination of outdoor and indoor environments, as well as a lack of consistent GPS positioning (Erath et al., 2016), however, for Switzerland this approach could be followed.

In the course of the thesis several elements for a land-use model are
developed. The residential mobility model and residential location choice model could be applied to a synthetic population of individuals and households. Hedonic models for residential asking prices have been developed by Lehner (2011). Nevertheless, given the importance of the HDB new sale market more research is required into the modelling of this market segment. Furthermore, a demographic model taking into account household formation is still required. Also, the residential location choice module would need be extended with a bidding module. Combined, these models can form the behavioural component of a land-use module for MATSim.

Although revealed preference data for residential location choice studies is commonly applied, there is a limited number of studies using stated preference data (e.g. Vyvere et al., 1998; Molin et al., 2002). There is critique that residential location choice might not be captured well by discrete choice models as it is choice not often made by households (Timmermans, 2006). Nevertheless, administering a stated preference or stated adaptation survey to recent movers can offer control over quality attributes of a dwelling, as well as introduce a variety of built environments that are currently limited available in Singapore, such as high-density mixed-use environments with varying building typologies. Taking this idea a step further, these environments can be visualized with procedural 3D models and immersive virtual reality. This concept does not only hold for Singapore. Given the ongoing debate of densification in Switzerland, but also other Western countries, immersive virtual reality can help to evaluate densification scenarios in virtual reality with stated preference design techniques.
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Conference on Computers in Urban Planning and Urban Management (CUPUM), Utrecht, July 2013.


Figure A.1: Trip distance distributions for home-work trips in Switzerland by municipality size and mode
Figure A.2: Trip distance distributions for home-shop trips in Switzerland by municipality size and mode.
Figure A.3: Beelines between start and end location of home-work trips as observed in smart card data

(a) Bee lines of trips between 0 and 15 minutes, n=127,303
(b) Bee lines of trips between 15 and 30 minutes, n=177,002
(c) Bee lines of trips between 30 and 45 minutes, n=158,803
(d) Bee lines of trips between 45 and 60 minutes, n=92,718
(e) Bee lines of trips between 60 and 75 minutes, n=35,132
(f) Bee lines of trips between 75 and 90 minutes, n=11,537
Figure A.4: Estimated distance decay functions for home education trip in Singapore and Switzerland

(a) Singapore, private transport
(b) Singapore, walk & public transport
(c) Switzerland, less than 50,000 inhabitants, private transport
(d) Switzerland, less than 50,000 inhabitants, walk & public transport
(e) Switzerland, more than 50,000 inhabitants, private transport
(f) Switzerland, more than 50,000 inhabitants, walk & public transport
## Table A.1: Estimated distance decay functions for Singapore

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Table A.2: Estimated distance decay parameters for Swiss municipalities, less than 50,000 inhabitants

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### Table A.3: Estimated distance decay parameters for Swiss municipalities, more than 50,000 inhabitants

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<th>Trip purpose</th>
<th>Distribution</th>
<th>By foot &amp; public transport</th>
<th>Private transport</th>
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<th>KS</th>
<th>AD</th>
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<th>KS</th>
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<td>0.26</td>
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<td>13431.07</td>
<td>0.11</td>
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<td>1866</td>
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Appendix B

Appendix to Chapter 8

B.1 Survey evaluation: spatial recollection

It should be noted that Singapore does not have a clear demarcation of neighbourhoods. For the survey it was chosen to use the administrative division of Singapore into planning areas and subzones used by the Department of Statistics and the Urban Redevelopment Authority.

Figure B.1 shows an example of a question in the survey in which respondents were to select one or more areas. When clicking an area, this area would change colour to indicate that it was selected. Respondents were also able to select areas from a drop-down list. Subsequently, sub zones would be listed belonging to this area would be presented as a multiple choice question. For several subzones, the roads demarcating the sub-zone would be stated, if the name was ambiguous (i.e. subzone-II, subzone - west, subzone - east).

Table B.1 provides an overview of some of the spatial questions in the survey. Two questions inquired about exact address details: a question concerning the location of the previous dwelling and a question concerning the location of the current dwelling. In both cases, the survey zoomed down on higher levels of detail, by starting at the planning area and ending with the postal code; every building in Singapore has an unique postal code. To reduce the survey burden, no validation was performed whether a postal code existed and whether it matched the planning area and subzone. In addition, given the speed of Singapore’s development, certain postal codes would be non-existent in our postal code database: over 270 postal codes were geo-coded after the survey was executed.

Table B.1 highlights some of the issues encountered when evaluating the postal code. In the case of the current dwelling, respondents filled out an
existing postal code in 95% of the cases. This postal code was located in the correct planning area in 77% of the cases. Indicating the correct subzone proved to be more difficult for respondents: only in 38% of the cases, the postal code matched the subzone. The postal code of the previous dwelling only matched the planning area in 77% of the cases.

Figure B.2 provides a further analysis of the cases where the postal code did not match the planning area. In 25% of the cases, the postal code of the current dwelling is located within 500 meters of the boundary of the correct planning area; approximately another 25% was within 2 kilometres of the
Table B.1: Evaluation of spatial questions

<table>
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<th>Current dwelling</th>
<th>Previous dwelling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Number of respondents</td>
<td>1107</td>
<td>-</td>
</tr>
<tr>
<td>Postal code exists</td>
<td>1045</td>
<td>94.4</td>
</tr>
<tr>
<td>Postal code inside planning area</td>
<td>853</td>
<td>77.1</td>
</tr>
<tr>
<td>Postal code inside subzone</td>
<td>429</td>
<td>38.8</td>
</tr>
</tbody>
</table>

Figure B.2: Distance in kilometre between stated planning area boundary and stated postal code for the current and previous residence

correct planning area. Respondent’s seem to have more issue recollecting the planning area of the previous dwelling; the distance distribution is slightly more skewed to the right.

Figure B.3 provides a further analysis of the ability of the respondent to pinpoint the correct subzone. When respondents state the correct planning area, they were able to name a planning area within 1.5 kilometres of the correct subzone in 90% of the cases. When respondent’s postal code did not match the correct planning area, they were still able to select a nearby subzone.

Based on this analysis, reference points for the respondent’s current and
previous dwelling were introduced (Table B.2):

1. When the postal code was within the correct planning area, the postal code was used as the respondent’s reference point;
2. When the postal was within 4 kilometres of the planning area, the postal was used as the respondent’s reference point;
3. When the postal was located further than 4 kilometres from the planning area, other address fields were inspected more closely. If these address fields matched the postal code, the postal code was used as a reference point;
4. The postal code was imputed when other address fields provided an exact indication of the address or when the postal code appeared to wrongly entered. This issue appeared more frequently with the postal code of the previous residence.
5. When the postal code was located further away than 4 kilometres of the planning area and other fields did not provide a sufficient
indication of the address the centroid of the planning area (previous dwelling) and the centroid of the subzone (current dwelling) was used as reference point.
6. When the postal code did not exist and other fields did not provide a sufficient indication of the address the centroid of the planning area (previous dwelling) and the centroid of the subzone (current dwelling) was used as reference point.

### Table B.2: Overview of geocoding process

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<td>657</td>
</tr>
<tr>
<td>n</td>
<td>77.1</td>
<td>65.0</td>
</tr>
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<td>Postal code within 4km of planning area</td>
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<td>134</td>
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<td>13.3</td>
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<td>32</td>
<td>31</td>
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<td>3.1</td>
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<tr>
<td>Postal code imputed</td>
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<td>46</td>
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<tr>
<td>n</td>
<td>1.4</td>
<td>4.6</td>
</tr>
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<td>Postal code further away than 4km; other fields do not match</td>
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<td>17</td>
</tr>
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</tr>
<tr>
<td>Postal code does not exist; other fields do not provide indication</td>
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<td>125</td>
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<td>n</td>
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Appendix C

Appendix to Chapter 9
Figure C.1: Comparison of respondents’ age at the time of moving to the current residence in the incidence survey and main survey

Figure C.2: Relationship of respondent to fellow household member(s)
Table C.1: Classification of movers according to changes in household structure

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<th>%</th>
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<td>With parents</td>
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<td></td>
</tr>
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<td>No</td>
<td>44</td>
<td>4.4</td>
</tr>
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<td>No</td>
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<td>0.8</td>
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<tr>
<td>Nest-leaver: Couple</td>
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<td>No</td>
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<td>13.7</td>
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<tr>
<td>Nest-leaver: Couple</td>
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<td>Yes</td>
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<td>16.1</td>
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<td>Yes</td>
<td>95</td>
<td>9.4</td>
</tr>
<tr>
<td>With parents: Single parent</td>
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<td>Yes</td>
<td>4</td>
<td>0.4</td>
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Figure C.3: Chosen dwelling type & tenure versus classification of households

[Diagram showing the relationship between household structure, current dwelling type & tenure, and frequency]

Household structure

Current dwelling type & tenure

Frequency

- HDB New sale – First-timer
- HDB New sale – Second-timer
- HDB Resale – First-timer
- HDB Resale – Second time or more
- HDB – Rental
- HDB – Other
- Private – Sale
- Private – Rental
- Private – Other

Appendix C. Appendix to Chapter 9
This was the only area with my household's preferred dwelling type.

The upkeep and maintenance of the block is good.

The number of rooms of the dwelling suits my/our needs.

The layout of the dwelling appealed to me.

The furnishing of the dwelling appealed to me.

The facilities and amenities of the building (i.e., gym, pool) are good.

The dwelling was in our price range.

The dwelling was available.

The dwelling is an attractive investment.

The architecture of the building/site appealed to me.

Scenic attractive area.

Proximity to recreation facilities.

Proximity to public transport.

Proximity to primary school.

Proximity to daycare.

People of similar age and background.

Parents/parents-in-law staying in this area.

My household was limited by the availability of HDB flats.

It is a dwelling with high quality fixtures and fittings.

Friendly layout of neighbourhood for walking and cycling.

Family/friends staying in this area.

Familiarity with the area.

Community feeling.

Close to my work.

Close to my partner/spouse's work.

Frequency
Appendix D

Appendix to Chapter 10

D.1 Search preferences
Figure D.1: Preferred minimum, ideal and maximum number of rooms.
Figure D.2: Preferred floor level by chosen dwelling type and tenure.

Figure D.3: Search channels by chosen dwelling type and tenure.
D.2 Matching revealed moves with transaction data

In the previous chapter respondents’ previous and current location of residence was matched against an address registry. In this chapter, we aim to match respondents moves to actual transactions. To these means, a comprehensive database of transactions was compiled. Respondents moves were matched with these transactions.
Figure D.5: Matched purchase date to year of move of survey response

Figure D.6: Matched price of transaction to survey response
Figure D.7: Matched number of rooms of transaction to survey response
Appendix E

Appendix to Chapter 11

E.1 Distances

The distance to the primary school for household members attending primary school is presented in Figure E.1. Respondents purchasing new sale for the second time live closest to primary school. Respondents moving to HDB Rental tend to live close to primary school as well.

Figure E.1: Chosen dwelling type & tenure and distance to primary locations
Figure E.2: Chosen dwelling type & tenure and distance to primary activity locations
Appendix F

Modeling

F.1 Multinomial Logit Model

The most commonly used discrete choice model is the Multinomial Logit (MNL) Model due to its ease of estimation and simple mathematical structure (McFadden, 1974). It is based on the assumption that the random terms, often called error terms or disturbances, are identically and independently (i.i.d.) Gumbel distributed. The choice probability of each alternative can be calculated as:

$$ P(i|C_q) = \frac{e^{V_{iq}}}{\sum_j e^{V_{jq}}} $$

(F.1)

Within the discrete choice framework, a decision-maker chooses from a set of alternatives. Each alternative is assumed to have a number of attributes. Each attribute has a level of utility or disutility, which capture the costs and benefits of an alternative; the utility $U$ of an alternative $i$ for a decision-maker $q$ is defined by:

$$ U_{iq} = V_{iq} + \varepsilon_{iq} = f(\beta_i x_{iq} + \varepsilon_{iq}) $$

(F.2)

with a deterministic part $V_{iq}$ that consists of a function $f$ of the vector $\beta_i$ of taste parameters and the vector $x_{iq}$ of attributes of the alternative, the decision-maker and the choice situation. In addition, socio-demographic attributes of decision-maker $q$ can be included in the deterministic part of the utility function. The non-deterministic, non-observable part of the utility function is captured by $\varepsilon_{iq}$. 
Model estimation results can be interpreted and evaluated in several ways (e.g., Louviere et al., 2000; Train, 2003). First, the parameter estimate $\hat{\beta}_{ik}$ of attribute $k$ in expression $V_i$ of alternative $i$ can be interpreted as the weight of the attribute in the utility expression by multiplying $\hat{\beta}_{ik}$ by the mean or median value of the attribute $X_i$.

Also, discrete choice models can be used to derive estimates of the willingness-to-pay (WTP) or willingness to accept (WTA) of an individual to obtain a benefit or avoid a cost. In a linear model, where each attribute is associated with a single parameter, the ratio of two parameters is the WTP or WTA, holding all other constant. If one of the attributes is measured in monetary units, the ratio can be interpreted as a valuation.

Finally, models can be evaluated by means of the responsiveness of market shares to changes in each attribute. Under the assumption that utility is attribute $z_{iq}$ with $\beta_z$, a single point elasticity for a continuous variable in the MNL model can be calculated as:

$$E_{iz_{iq}} = \beta_z z_{iq} (1 - P_{iq}) \quad (F.3)$$

Preferably, equation $F.3$ is evaluated for each individual $q$ and then aggregated, weighting each individual’s estimated probability of choice (Louviere et al., 2000):

$$E_{X_{jkq}}^{\hat{p}_i} = \frac{\sum_{q=1}^{Q} \hat{p}_{iq} E_{X_{jkq}}^{P_{iq}}}{\sum_{q=1}^{Q} \hat{p}_{iq}} \quad (F.4)$$

For computing aggregate level elasticity effects of ordinal and dummy variables the procedure outlined by Bhat and Pulugurta (1998) is applied. To compute the elasticity of an ordinal variable (e.g., number of members in household) the value of the ordinal variable is increased by one unit for each household and the relative change of expected aggregate shares is
computed as follows:

\[ E_{X_k}^{MS(i)} = \frac{MS^{SC}(i) - MS(i)}{MS(i)} \]  

where \( MS(i) \) and \( MS^{SC}(i) \) are the shares of alternative \( i \) before and after the ordinal variable are increased by one unit.

To compute the elasticity of a dummy variable (e.g. bus stop within 500 meters) the value of the variable is changed to one for the sub-sample of observations for which the variable takes a value of zero and to zero for the sub-sample of observations for which the variables takes a value of one. The shifts in expected aggregate shares in the two sub-samples are summed after reversing the sign in the second sub-sample. Subsequently, the effective proportional change in expected aggregate shares in the entire sample is computed due to the change in the dummy variable from 0 to 1. The aforementioned measures make it possible to compare not only models on estimated on the same data source but also model estimate from different studies and data sources.
Appendix G

Resume & publications
G.1 Resume

PERSONAL INFORMATION

<table>
<thead>
<tr>
<th>Full name</th>
<th>Michael A.B. van Eggermond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date &amp; Place of birth</td>
<td>September 14, 1980, Breda, the Netherlands</td>
</tr>
<tr>
<td>City of residence</td>
<td>Singapore</td>
</tr>
<tr>
<td>Marital state</td>
<td>Married, two children</td>
</tr>
<tr>
<td>Nationality</td>
<td>Dutch</td>
</tr>
<tr>
<td>Cell phone</td>
<td>+65 9048 6808</td>
</tr>
<tr>
<td>E-mail</td>
<td><a href="mailto:eggermond@ivt.baug.ethz.ch">eggermond@ivt.baug.ethz.ch</a></td>
</tr>
</tbody>
</table>

PROFESSIONAL EXPERIENCE

2016 (jun) - Now Senior researcher and project coordinator of the group 'Engaging Mobility'. Our main research question: What make walking and cycling viable in the tropics?. To these means, we employ immersive virtual reality and use virtual reality for engagement and surveys.

2016 (jun) - Now CTO at Erveco / Erath-Rusterholz, van Eggermond. Project highlights include the measurement of pedestrian potential in Swiss agglomerations, awarded by the SVI (Swiss Association of Transport Engineers).

2011 (feb) - 2016 (jun) Singapore-ETH Centre - Future Cities Laboratory. Researcher at the first foreign centre of the ETH Zurich, located in Singapore. Involved in several iterations of the development of MATSim Singapore, an agent-based transport demand model and the measuring of walkability in Singapore.

2010 - 2011(jan) INITI8 B.V.: R&D Manager: Coordinating the research and development activities, both operational and strategic.

2008 - 2010 INITI8 B.V.: Consultant. Projects in various sectors (healthcare, inland shipping, post handling, mainports) and with various stakeholders (municipalities, provinces, privately owned companies) with as main theme logistics, intra-organizational optimization, data visualization and performance measurement.
2007 ETH Zurich, Zurich; Master thesis in the transport planning group of Professor Kay W. Axhausen and under supervision of Professor Bovy. Topic: Consumer choice behavior and strategies of air transportation modeling. The thesis concerns the modeling of itinerary choice behavior, by applying discrete choice theory and addresses potential application areas of such models.

2006 INITI8 B.V., Rotterdam; Data-analyst and simulation consultant for several sectors, such as juvenile care. A system dynamics approach is used.

2006 TNO & TU Delft, Master project; A three month investigation towards the potential of on-demand air transportation in Europe (grade 8.5/10).

2005-2006 INITI8 B.V. Internship and bachelor thesis, Rotterdam; the handling and planning of chemical tankers in the port of Rotterdam. Project conducted under supervision of Prof A. Verbraeck, TU Delft.

**EDUCATION**

2011-2017 PhD ETH Zurich 'Diversity, accessibility and its impact on vehicle ownership and residential location choices’ examined by Prof Kay W. Axhausen (ETH Zurich), Prof Harvey Miller (Ohio State) and Dr Alexander L. Erath (ETH Zurich)


2007 ETH Zurich, Master Courses Econometrics, Microeconomics, Energy Economics (Average grade 5/6)

2005 Erasmus student exchange, ETH Zurich, Master Courses Civil Engineering, Social Sciences and Management, Technology and Economics. (Average grade 5/6)

2000-2006 Bachelor Systems Engineering, Policy & Management, Delft University of Technology. Bachelor thesis within the Systems Engineering department (Average grade 7/10, Bachelor thesis 8/10)

1999-2000 Civil Engineering, Delft University of Technology.

EXTRACURRICULAR

2013 - Now  Member High-Tech Committee, Dutch Chamber of Commerce, Singapore
2009 - Now  Member Democrats ’66, liberal democratic political party in the Netherlands.
2002-2003  Treasurer Lustrumbook Commission., KSV Sanctus Virgilius, Delft
2000-2001  President Henk Commission (Sound & Light), KSV Sanctus Virgilius, Delft

SKILLS

Languages
Dutch: Mother tongue
English: both good oral & written knowledge
German: both good oral & written knowledge (Goethe Institut C1, grade 85 of 100)
Swiss German: good oral knowledge
Polish: average oral knowledge

Software
ESRI ArcMap, ESRI Collector, QGIS, PostGIS, Biogeme, SPSS, Rockwell Arena, Powersim & other simulation packages, JAVA, Visual Basic, Flex, Databases (Postgres, MySQL, MS SQL), SSIS, Tableau, Web development (CSS, HTML, Wordpress, Javascript, Apache), LaTeX. And of course MS Office (Word, Excel, Access, Powerpoint, Visio)

SUPERVISED STUDENTS


Laboratory, Singapore.


G.2 Publications

REFEREED JOURNAL PAPERS


PROFESSIONAL JOURNAL PAPERS


REFEREED CONFERENCE PAPERS


CONFERENCE PAPERS


WORKING PAPERS


NEWSPAPERS & MAGAZINES


**TV & MEDIA APPEARANCES**


Sim, J. (2017) Smart Cities 2.0 (featured on Channels News Asia), March 2017.
