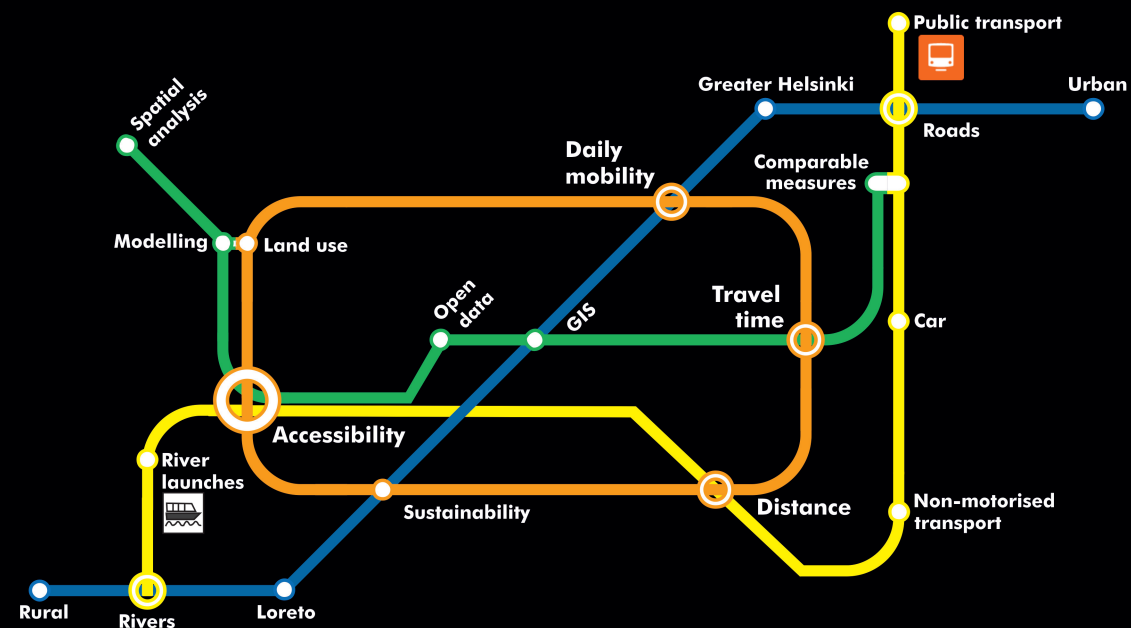




Accessibility has become an important conceptual tool for understanding sustainable urban transportation and human influence on natural systems at different spatial scales. Quantitative accessibility information is needed to support different spatial planning processes, and recent development in data availability and computational methods now enable a level of detail in analysis that was unfeasible in the past. In this thesis I develop accessibility analysis methods and address accessibility questions in two different contexts: in the rural Peruvian Amazonia where the extensive river network forms the backbone of regional transportation and in the capital region in Finland where my focus is on urban daily mobility.



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MARIA SALONEN

Analysing spatial accessibility patterns with travel time and distance measures: novel approaches for rural and urban contexts

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ACADEMIC DISSERTATION

To be presented, with the permission of the Faculty of Science of the University of Helsinki, for public examination in the lecture hall 5 of the Main Building of the University of Helsinki, on November 7th, 2014, at 12 o'clock.

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ABSTRACT

Accessibility plays a key role in shaping the patterns of human activity on all spatial scales. Accessibility questions are particularly topical now that cities around the world strive for more sustainable urban mobility and information on human influence on natural systems is needed in order to better understand processes of global environmental change. Following these lines of development, supporting different spatial planning processes with quantitative accessibility information has become increasingly important, and different accessibility analysis methods are actively being developed for this purpose. Furthermore, availability of new types of data and increasing computational power enable novel approaches and a level of detail in analysis that were unfeasible in the past.

This thesis addresses accessibility questions through five case studies in two different contexts. Two case studies take place in the rural Peruvian Amazonia (Loreto region) where the extensive river network forms the backbone of regional transportation and people's daily mobility. The other three case studies are conducted in the capital region in Finland (Greater Helsinki), and the focus of these studies is on urban environments.

The contribution of my work is both methodological and contextual; I aim at finding novel data sources for spatial accessibility analyses and further developing methods for quantifying accessibility as distances and travel times. On the other hand, I aim at (visually) describing and understanding the spatial patterns of accessibility in my study areas and at analysing and discussing the implications of accessibility for the spatial organisation of land-use and people's daily mobility.

My results show that realistic accessibility analyses require a consideration of different travel modes and regionally specific transport network properties. In fluvial transport networks, travel time analysis is particularly sensitive to river channel types, direction of movement and seasonality. In urban settings the door-to-door approach for multimodal travel time calculations gives more realistic results than in-vehicle travel time only, and it also makes the different travel modes mutually comparable. The value of the more advanced quantification methods becomes particularly visible when the results obtained from the accessibility calculations are further applied in new analyses. The use of simple Euclidean distances may, however, be justified in situations where appropriate data for more advanced analysis is lacking, but knowing the limitations and simplifying assumptions of these measures is important when applying them.

The key contextual findings of this thesis are based on quantitative descriptions and visualisations of the spatial patterns of accessibility in the case study areas. Quantitative data on accessibility also serve as an input for analyses of human livelihoods (such as modelling of

potential production zones for different agricultural produce in Loreto) and land-use pressure (such as Amazonian deforestation modelling). My results furthermore show how accessibility to services and other daily activities is an important factor influencing urban residents' travel behaviour and its environmental sustainability in Greater Helsinki.

Finally, this thesis provides examples of how different types of data sources and their innovative combinations can be used in accessibility analyses. In the case studies I utilize and thus introduce freely available computational tools for detailed multimodal travel time analysis.

Keywords: Amazonia; Accessibility; Daily mobility; Distance; Data; GIS; Greater Helsinki; Travel time

TIIVISTELMÄ

Alueiden ja toimintojen saavutettavuus ohjaa ihmisten toimintaa sekä paikallisesti että globaalisti. Saavutettavuuskysymykset ovat ajankohtaisia urbaanista liikkumisesta keskusteltaessa, kun kaupungit eri puolilla maailmaa pyrkivät saamaan asukkaidensa arkiliikkumisesta ekologisesti ja sosiaalisesti kestävämpää. Toisaalta saavutettavuusanalyysit auttavat hahmottamaan ihmisen aiheuttamaa maankäytön painetta eri mittakaavatasoilla, mikä puolestaan on oleellista globaalien ympäristömuutoksen ymmärtämiselle. Kvantitatiivisen saavutettavuustiedon rooli suunnittelun ja päätöksenteon tukena onkin viime aikoina vahvistunut, ja uudentyypisten aineistolähteiden parempi saatavuus sekä laskennallisten menetelmien nopea kehitys ovat osaltaan mahdollistaneet saavutettavuuden entistä tarkemman mittaamisen.

Tämä väitöskirja käsittelee saavutettavuuskysymyksiä viiden tapaustutkimuksen ja kahden keskenään hyvin erilaisen tutkimusalueen kautta: Kaksi väitöskirjan artikkeleista käsittelee Loreton maakuntaa Perun Amazoniassa, jossa ihmisten ja tavaroiden liikkuminen perustuu suurelta osin alueen laajaan jokiverkostoon. Muut kolme artikkelia sijoittuvat Suomen pääkaupunkiseudulle (Helsinki, Vantaa, Espoo, Kauniainen), ja niissä tarkastellaan saavutettavuutta urbaanissa ympäristössä.

Työni anti tieteelliseen keskusteluun on yhtäältä menetelmällinen ja toisaalta kontekstisidonnainen. Pyrin löytämään uudenlaisia aineistolähteitä alueellisen saavutettavuusanalyysin tarpeisiin ja kehittämään kvantitatiivisia saavutettavuuden mittaamisen menetelmiä erityisesti etäisyyksien ja matka-aikojen osalta. Toisaalta tavoitteenani on (erityyppisten visualisointien avulla) kuvata ja ymmärtää saavutettavuuden alueellisia rakenteita tutkimusalueillani ja sen myötä keskustella saavutettavuuden merkityksestä tutkimusalueideni maankäytölle ja asukkaiden arkiliikkumiselle.

Tulokseni osoittavat, että eri kulkutapojen ja liikenneverkostojen paikallisten erityispiirteiden huomioiminen ovat avainasemassa, kun saavutettavuutta halutaan tarkastella mahdollisimman realistisesti. Jokiverkostoon tukeutuvien liikenneverkostojen osalta matka-aikalaskennassa täytyy huomioida jokityypit, navigoinnin suunta sekä vuodenaikojen vaikutus. Uraanissa ympäristössä ovelta-ovelle –lähestymistapa eri kulkutavat huomioivissa matka-aikalaskennoissa johtaa todenmukaisempiin tuloksiin kuin pelkän ajoajan huomioiminen. Toisaalta tällainen lähestymistapa mahdollistaa myös kulkutapojen keskinäisen vertailun menetelmällisesti koherentilla tavalla. Kehittyneempien laskentamenetelmien arvo tulee esiin erityisesti silloin kun saavutettavuusanalyysien tuloksia sovelletaan jatkoanalyseissa, mutta tulokseni osoittavat myös, että yksinkertaisten euklidisten etäisyyksien käyttö saavutettavuusmittareina saattaa olla perusteltua, jos aineistoja kehittyneempään laskentaan ei ole saatavilla. Euklidisiin etäisyyksiin perustuvia mittareita hyödynnettäessä on kuitenkin syytä muistaa niiden rajoitteet ja yksinkertaistavat oletukset.

Keskeisimmät tutkimusalueisiini liittyvät tulokset perustuvat kvantitatiivisiin kuvauksiin ja visualisointeihin alueiden saavutettavuusrakenteista. Olen hyödyntänyt laskennallista saavutettavuustietoa myös Loreton jokivarren kylien asukkaiden elinkeinojen analysointiin sekä maankäytön paineen, erityisesti deforestaation mallinnukseen. Suomen pääkaupunki-

seudun tapaustutkimusten tuloksen osoittavat, kuinka päivittäisten palveluiden saavutettavuus vaikuttaa pääkaupunkiseutulaisten arkiliikkumiseen ja sen ekologiseen kestävyYTEEN.

Väitöskirjani tapaustutkimukset antavat myös esimerkkejä siitä, kuinka erityyppiset aineistolähteet ja niiden innovatiivinen yhdistely voivat tuoda uusia ulottuvuuksia saavutettavuusanalyysiin. Lisäksi työni hyödyntää ja samalla esittelee avoimesti saatavilla olevia laskennallisia työkaluja yksityiskohtaisiin kulkutapakohtaisiin matka-aika-analyysiin.

Asiasanat: saavutettavuus; matka-aika; etäisyys; arkiliikkuminen; paikkatieto; aineistolähteet; Amazonia; pääkaupunkiseutu

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In Nørrebro, København, September 23, 2014

Maria Salonen

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the five peer-reviewed articles listed below. The papers are referred to with their roman numerals in the text.

Paper I: Salonen, M., T. Toivonen, J.-M. Cohalan & O. Coomes (2012). Critical distances: Comparing measures of spatial accessibility in the riverine landscapes of Peruvian Amazonia. *Applied Geography* 32: 2, 501-513.

Paper II: Salonen, M., E. Maeda & T. Toivonen (2014). Evaluating the impact of distance measures on deforestation simulations in the fluvial landscapes of Amazonia. *Ambio* 43: 6, 779-790.

Paper III: Salonen, M. & T. Toivonen (2013). Modelling travel time in urban networks: comparable measures for private car and public transport. *Journal of Transport Geography* 31, 143–153.

Paper IV: Lahtinen, J., M. Salonen & T. Toivonen (2013). Facility allocation strategies and the sustainability of service delivery: Modelling library patronage patterns and their related CO₂-emissions. *Applied Geography* 44, 43-52.

Paper V: Salonen, M., A. Broberg, M. Kyttä & T. Toivonen (2014). Do suburban residents prefer the fastest or low-carbon travel modes? Combining public participation GIS and multimodal travel time analysis for daily mobility research. *Applied Geography* 53, 438-448.

Author's contribution

	I	II	III	IV	V
Original idea	MS, TT, J-MC, OC	MS, EM, TT	MS, TT	JL, MS, TT	MS, AB, MK, TT
Study design	MS, TT, J-MC, OC	MS, EM, TT	MS, TT	JL, MS, TT	MS, AB
Data collection	MS, JMC	MS	MS	JL, MS	MS, MK
Analysis	MS, JMC	MS, EM	MS	JL, MS	MS, AB
Manuscript preparation	MS, TT, OC, J-MC	MS, EM, TT	MS, TT	JL, MS, TT	MS, AB, MK, TT

MS = Maria Salonen; TT = Tuuli Toivonen; J-MC = Jean-Michel Cohalan; OC = Oliver Coomes; EM = Eduardo Maeda; JL = Jaani Lahtinen; AB = Anna Broberg; MK = Marketta Kyttä

ABBREVIATIONS

API	Application Programming Interface
CO ₂	Carbon Dioxide
GIS	Geographic Information Science / Geographic Information System
GHG	Greenhouse Gas
HRT	Helsinki Region Transport
ICT	Information and Communication Technologies
LLDB	Library Loan Database
LUCC	Land-use and Land-cover Change
NMT	Non-motorised Transport
OD	Origin-destination
OSM	OpenStreetMap
PPDAC	Problem, Planning, Data, Analysis, Conclusions
PPGIS	Public Participation GIS
PSS	Planning Support System
PT	Public Transport
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission

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Figure 2	Case study areas: Location and crucial contextual differences
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1. INTRODUCTION

Spatial accessibility – defined as the way in which land-use and transport systems allow people to reach diverse activities – has an indisputable significance to the functioning of our societies and to the well-being of people and the environment. The ability to access places and activities provides fundamental social and economic benefits for individuals; it enables both interaction with other people and participation in necessary and voluntary daily activities. Broadly speaking, accessibility has a profound impact on the overall quality of life (Wachs & Kumagai 1973; Doi et al. 2008; EEA 2009; Cao 2013), and it plays a key role in shaping the spatial patterns of human activity at all spatial scales (Pooler 1987; Neutens et al. 2011; Sheng et al. 2012; Levers et al. 2014).

Some current trends in our societies make the questions of accessibility particularly intriguing both in urban and rural contexts:

Increased mobility and flows of people, goods and information have become defining features of contemporary urban life (Sheller & Urry 2006; Bertolini et al. 2008; Batty 2011). Increasingly polycentric urban forms, together with other structural changes of growing metropolitan areas, have made the patterns of daily mobility more and more complex (Parr 2005; Martens 2006; Gutiérrez & García-Palomares 2007; Batty 2008). Although the continuous advancements in telecommunication possibilities have raised speculation about the possibly declining relevance of physical interactions, recent research actually shows that rather than just replacing transport, information and communication technologies (ICT) actually seem to increase physical mobility (e.g., Bertolini et al. 2008). Accessibility within and among urban regions is a prerequisite for mobility, and accordingly, it is seen as a key factor in promoting interactions and the flow of ideas, thus enhancing the vitality, innovativeness and economic performance of urban regions (Priemus & Konings 2000; Banister 2011; Pentland 2014).

Also in rural settings, transport provision and accessibility are seen as major promoters of economic development (although the relationship between the two is admittedly very complex) (Kansky 1963; MacKinnon et al. 2008; Agarwal et al. 2009). Indeed, accessibility to urban centres and product markets has a profound effect on the livelihood options and welfare of rural dwellers (Guimarães & Uhl 1997; Takasaki et al. 2001; Olsson 2009). Rural-to-urban transportation options furthermore influence the rural population's possibilities for education and healthcare (Vasconcellos 1997; Noor et al. 2003; Chen et al. 2011; Siedner et al. 2013; Yao et al. 2013).

At both ends of the urban-rural continuum, accessibility and transport are interwoven with a range of social and environmental concerns. Following enhanced transportation links, a growing urban population and increased personal mobility, urban sprawl has become a prominent challenge faced by cities all over the world (Robinson et al. 2005; EEA 2006; Sperandelli et al. 2013; Schneider & Mertes 2014). The combination of an increasingly

dispersed urban population and a growing need to reduce (public) service provision is a challenging equation from the accessibility and social equity point of view (Neutens et al. 2010; Seifolddini & Mansourian 2012). Furthermore, transportation is one of the main sources of urban greenhouse gas (GHG) emissions (Bertaud et al. 2011; Bulkeley 2013), and is associated with a range of other negative impacts such as congestion, road accidents, use of non-renewable energy, noise pollution and threat to human health (EEA 2013). Accordingly, striving for more sustainable urban mobility is a top policy goal in cities all over the world (European Commission 2007; Banister 2008; Deng & Nelson 2013; EEA 2013).

People in many rural areas, particularly in the Global South, struggle with relative immobility and chronic accessibility challenges owing to a lack of or poorly managed transport infrastructures (Nutley 1998; Porter 2002; Yao et al. 2013). Although ICT is anticipated to relieve the rural accessibility problem (Naude et al. 2005; Olsson 2012), the coverage of telecommunication networks is still limited in many rural regions (Williams et al. 2011), and hence, the need for physical connections between the rural hinterland and the urban core becomes even more pronounced. In biologically valuable tropical regions, accessibility is also closely linked with land use change (particularly deforestation) and loss of natural habitats (Lambin 1997; Overmars & Verburg 2005; Müller & Mburu 2009). The spatial patterns of accessibility and transportation networks direct the distribution of the rapidly growing population in these regions, and consequently, guide the anthropogenic threat to tropical ecosystems, protected areas, and biodiversity (Aubad et al. 2010; Laurance et al. 2014).

These lines of development are major challenges for contemporary politics, decision-making and planning. Given that accessibility is in many ways interwoven in the processes described above, supporting different types of planning processes (ranging from urban to regional planning, covering themes of transport, land-use and conservation) with adequate accessibility information has become increasingly topical and important. Indeed, accessibility is considered an essential conceptual tool for integrating land-use and transportation planning at urban scales (Bertolini et al. 2005; Curtis & Scheurer 2010; Geurs et al. 2012b) and for understanding land-use pressure in the tropics (Lambin 1997; Pan & Bilborrow 2005; Etter et al. 2006).

In order to make accessibility more than just a useful concept, appropriate methods and suitable data sources are needed for reliable quantitative accessibility analysis. The role of geoinformatics and geographic information systems (GIS) in accessibility analyses is increasingly important (Kwan & Weber 2003; Neutens et al. 2010), and new methods for accessibility modelling are actively being developed (Halden 2002; Curtis & Scheurer 2010; Geurs et al. 2012a; Hull et al. 2012). While previous studies had to accommodate methods to the limitedly available, often very coarse and aggregated data (Pirie 1979), today the availability of data (also at more disaggregated scales) is much better. Here, technological innovations (global and mobile positioning technologies in particular) (Zheng et al. 2008; Batty 2012; Wang et al. 2012) and recent movements for open data (Desouza & Bhagwatwar 2012; Berish 2013; Jäppinen et al. 2013) have played a major role. Diverse data sources combined with increased computational capacity make new kinds of analyses possible; in

particular, it is now feasible to analyse accessibility by different travel modes and at very high levels of detail. This challenges the relevance of traditional approaches relying on simple straight-line distances and car travel times, and hopefully provides more relevant input for a variety of different planning processes.

In this thesis, I address the themes outlined above in two different case study areas: the Loreto region in Peruvian Amazonia and Greater Helsinki in Finland. I have two types of objectives which are common for all case studies but manifest themselves in different ways in the different study contexts:

(1) Methodological objectives

- a. My aim is to *find novel data sources and innovative data combinations for spatial accessibility analyses*, and
- b. to *analyse different methods* for quantifying accessibility, as distances and travel times and *further develop these methods* to be better applicable particularly in my study areas.

(2) Contextual objectives

- a. I aim at (visually) *describing and understanding the spatial patterns of accessibility in my study areas*, and
- b. at *analysing and discussing the implications of accessibility for the spatial organisation of land-use and people's daily mobility*.

These research objectives are addressed by the five individual papers constituting this thesis:

Paper I compares different distance- and frequency-based measures of spatial accessibility and evaluates their usefulness in understanding accessibility in the Loreto region in Peruvian Amazonia. In the paper, we aim at understanding how river network properties and available transportation options affect the spatial patterns of accessibility. In addition, travel time based accessibility zones are visualised as potential production zones for locally important agricultural and non-timber forest products.

Paper II aims at understanding how different accessibility measures work as inputs for a land use and land cover change (LUCC) model. We construct a “retrospective” LUCC model that simulates deforestation from a hypothetical starting point of no deforestation to the present day deforestation pattern in the Loreto region. The core of the analysis is the systematic testing of the different accessibility measures (developed in paper I) as inputs for the LUCC model. We demonstrate how the selection and different combinations of accessibility measures impact simulation results, and finally assess which accessibility measure(s) (together with other variables) yield the most reliable deforestation simulations.

Paper III evaluates the comparability of different methods for calculating travel times by car and by public transportation in Greater Helsinki. In the paper, we first review commonly used approaches for travel time calculations and then systematically compare these approaches by constructing three computational travel time models for car and public transport (PT),

respectively. In these models, congestion, parking, public transport schedules, and complete travel chains from door to door are implemented to varying degrees. The different models are used for measuring travel times between different locations (from populated grid squares to daily travel destinations across the region). We compare the results of different models, assessing their suitability for studies that focus on modal accessibility disparity. Finally, the paper discusses the ways in which the different analysis methods affect the resulting travel times and trip distances on the one hand, and the range and spatial distribution of the observed modal travel time gaps on the other.

Paper IV compares the impacts of varying municipal service allocation strategies on residents' travel behaviour and the resulting carbon emissions in Greater Helsinki. Libraries are used as an example of a local public service. Spatially referenced library customer statistics provide information on the real-life customer flows from customers' homes (origins) to libraries (destinations). Based on a mode choice model, each library trip is allotted the most probable travel mode. We utilise methods developed in paper III for modelling travel routes between customers' home locations and the destination libraries, and convert the travel-mode specific travel chains into carbon dioxide (CO₂) values. We compare the "climate-optimal" library patronage patterns (i.e., situations where each customer would choose to use the library that is accessible from his/her home with minimum CO₂ emissions) with the real-life patronage patterns. Moreover, we examine the spatial distribution of CO₂ emissions between the different municipalities, which employ different strategies for planning and allocating their services.

Paper V presents a methodology that combines mapped survey responses (gathered using public participation GIS) and sophisticated multimodal routing analysis (computed with methods from paper III) to understand patterns of suburban residents' daily mobility. First we describe the basic characteristics (trip types, trip lengths and travel times) of suburban residents' travel behaviour in Greater Helsinki, and then analyse the residents' mode choices and their optimality in terms of travel time. In addition, we examine the carbon-intensity of potential mode choice mismatches where a comparatively slower travel mode is chosen for a particular trip.

2. CONCEPTUAL FRAMEWORK

2.1 Positioning the research

Theoretically and methodologically this thesis relies on an interdisciplinary mix between various interrelated subfields of geography (Fig. 1). Traditionally, questions of accessibility have been addressed in *transport* (and *economic*) *geographic* literature where the role of transport networks and accessibility are linked with regional (economic) development and people's travel behaviour. Logistics, as part of transport geography, is also a relevant framework for accessibility questions when it comes to the flow of materials and goods. Closely related to themes in transport geography, *urban geographers* have also actively used the concept of accessibility in understanding distribution of urban land-uses and residents' interactions in urban spaces. Accessibility is furthermore clearly linked with *environmental geography*, and to this thesis, the study of land change processes is of particular interest. Much of the methodological development for accessibility analysis has taken place within *geographic information science*, and *geographic information systems (GIS)* have had an instrumental role in attempts to quantify accessibility. In general, geographic information science is a cross-cutting field that provides analytical methods for all the above mentioned fields.

Accessibility considerations are highly relevant in spatial planning processes at urban and regional scales; hence, although this thesis is not directly linked to practical level planning, the discussion section touches upon the links between my results and planning practices (see Fig. 1).

Accessibility and *mobility* are central concepts that are dealt with throughout the thesis. In particular, the concept of accessibility is rather contested (e.g., Gould 1969; Geurs & van Wee 2004) and requires a quick review of the different ways in which it can be defined. Some of the frequently cited definitions of accessibility include “*the potential of opportunities for interaction*” (Hansen 1959); “*the degree to which two places (or points) on the same surface are connected*” (Ingram 1971); “*the ease with which any land-use activity can be reached from a location using a particular transport system*” (Dalvi & Martin 1976); “*the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)*” (Geurs & van Wee 2004); and “*the amount and the diversity of places of activity that can be reached within a given travel time and/or cost*” (Bertolini et al. 2005).

For this work, the definition of Geurs and van Wee (2004) is particularly relevant because it recognises the interplay between transport systems and land-use, and identifies the need to account for several transport modes. The definition of Bertolini et al. (2005), on the other hand, is useful since it recognised travel time as a meaningful component of accessibility.

The concept of mobility is closely related to accessibility. In transport geographic research, mobility is generally referring to the *ability* of an individual to move between different activities (Hanson & Giuliano 2004; Hine 2008). In this thesis, the concept is used to refer to

the *realised movement* between different places. By daily mobility I mean travel that occurs in order to accomplish everyday tasks, such as work, shopping, or leisure activities. So, following Hodge's (1997) formulation; accessibility is essentially a measure of potential, and mobility is essentially a measure of behaviour.

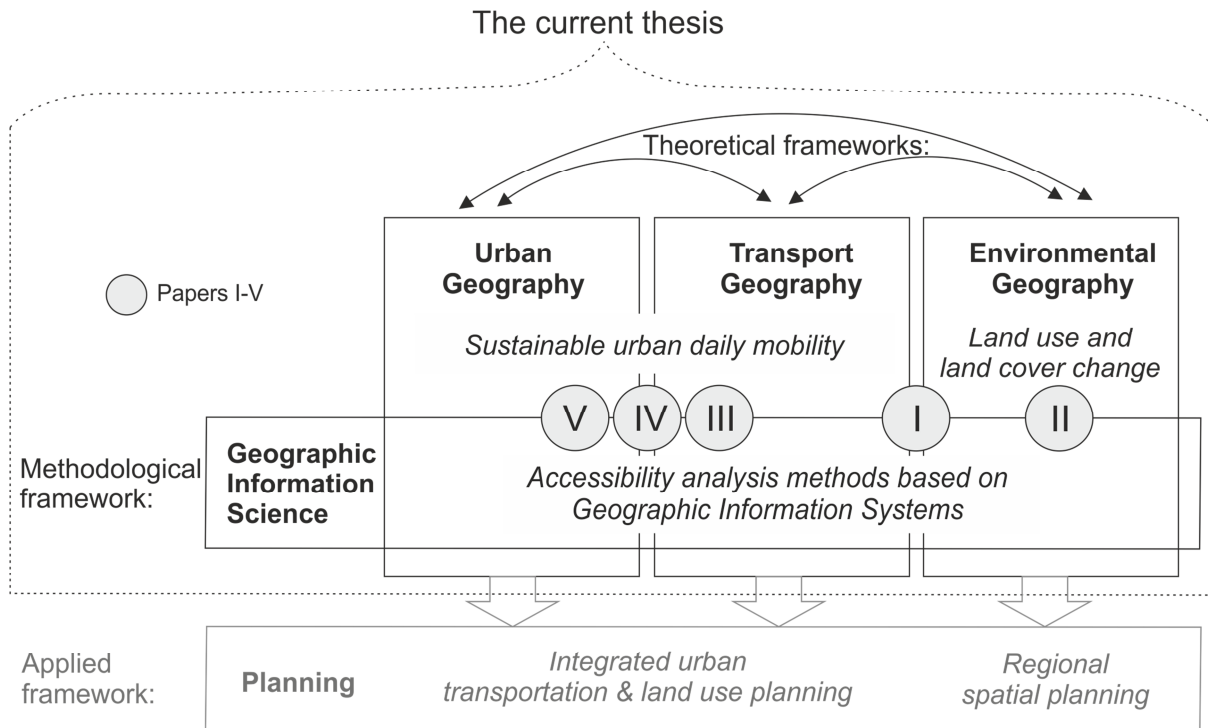


Figure 1. Positioning the current thesis within different subfields of Geography.

2.2 Regional-level considerations: Accessibility as a key driver of land-use patterns and land changes

The relationship between accessibility and land-use has been explored by several location theories since von Thünen's times in the 19th century (von Thünen 1827 / Hall 1966; Dicken & Lloyd 1990). In these theories the location of different economic activities was explained as a function of distance (or transport costs, and more generally, accessibility) from market centres. Later these ideas have been employed by researchers who are studying land changes, particularly tropical deforestation (Chomitz & Gray 1996; Angelsen & Kaimowitz 1999; Geoghegan et al. 2001; Verburg et al. 2004; Angelsen 2007).

Land-use and land cover change (LUCC) are key contributors to global environmental change (Keys & McConnell 2005; Huajun et al. 2009). Although many of the LUCC impacts are positive from the human point of view (increased food production, livelihood security, etc.; see Lambin et al. 2003), LUCC also drastically impacts the regional and global climate (McAlpine et al. 2009), leads to soil degradation (Sharma et al. 2011) and biodiversity loss (Velázquez et al. 2003), and ultimately reduces the ability of natural systems to support human needs (Lambin et al. 2003; Chhabra et al. 2006; Priess et al. 2007). In order to better understand causes and consequences of land changes, the past few decades have witnessed a

rapid development in methodologies and data gathering related to spatial simulation of LUCC processes (Huajun et al. 2009; Hibbard et al. 2010).

Advanced LUCC models typically employ both environmental and anthropogenic factors to explain the location and magnitude of land changes. Owing to advances in remote sensing technologies and several global-level environmental monitoring campaigns (see Achard et al. 2007; Batjes 2009; Verburg et al. 2011b), data on basic environmental variables, such as slope, precipitation, vegetation cover and soils are relatively easily available. Anthropogenic variables, on the other hand, are harder to quantify, and the availability of human-related data for LUCC modelling purposes is much more restricted (Veldkamp & Lambin 2001; Verburg et al. 2011a). Physical accessibility is one of the most commonly used surrogates for human pressure on the environment in land change studies, and it is regarded as one of the strongest predictors of the location of land changes (Mertens & Lambin 2000; Laurance et al. 2002; Nagendra et al. 2003; Soler et al. 2009). Particularly, the proximity to (paved) roads and to market centres has proven to be an efficient predictor of the location of land changes (e.g., Alvarez & Naughton-Treves 2003; Kirkby et al. 2006). While many LUCC modelling efforts rely on Euclidean distances as a surrogate for human activity (e.g., Jasinski et al. 2005; Kirby et al. 2006; Soares-Filho et al. 2006; Pan et al. 2007; Kim 2010; Thapa and Murayama 2011), the need for more advanced ways of quantifying accessibility is recognised among LUCC modellers (Mann et al. 2010; Verburg et al. 2011a).

2.3 City-level considerations: Accessibility as a novel planning premise, promoting sustainable daily mobility

Sprawling urban structures and reliance on private cars are seen as major problems of many contemporary cities (Kenworthy & Laube 1999; Banister 2008; Greca et al. 2011). Indeed, residents' travel mode choices have a considerable impact on the GHG emissions (particularly CO₂) resulting from daily mobility, as well as on the overall environmental sustainability of urban travel (OECD 2010; Bertaud et al. 2011). Accordingly, reducing travel distances and supporting a modal shift from the private car to more sustainable travel modes have become key considerations in sustainable urban development (Schwanen et al. 2004; Banister 2008; Curtis & Mellor 2011; EEA 2013).

The spatial organisation of urban land-uses and transport infrastructure plays an important role in shaping residential mode choices and distances travelled. The interrelationships between urban form and travel behaviour are, however, unquestionably very complex, and recent decades have witnessed a lively debate on how the urban form actually affects residents' travel patterns (e.g., Newman & Kenworthy 1989; Handy 1996; Cervero & Wu 1997; Dieleman et al. 2002; Næss & Jensen 2004; Næss 2005, 2006; Rodrigue et al. 2006; Maat & Timmermans 2009). While researchers have not reached a consensus on what would be the most sustainable urban form, empirical evidence from many cities suggests that high-density cities and mix-use neighbourhoods where services and employment opportunities are located close to residents tend to reduce average travel distances and increase the use of more sustainable travel modes (e.g., Newman & Kenworthy 1989; Rajamani 2003; Kerr et al. 2007;

Vance & Hedel 2007; Karathodorou et al. 2010; EEA 2013; Holz-Rau et al. 2014). The causality of the relationship between urban form and travel behaviour is, however, partly questioned because of the confounding effect of residential self-selection (i.e., residents choosing a living environment that suits their transportation preferences) (see Mokhtarian & Cao 2008).

Acknowledging the role of urban form in guiding travel behaviour, transportation and land use planning solutions play a key role in supporting sustainable urban living. In order to plan for more sustainable cities, many scholars suggest that accessibility should become a leading idea and concept in integrated land-use and transport planning (e.g., Bertolini et al. 2005; Curtis 2011). Planning for accessibility (rather than mobility) would help us on the way to more sustainable cities (Curtis 2008; Straatemeier 2008). Accordingly, development of suitable methodologies and tools for analysing and quantifying accessibility to support different planning tasks is particularly topical now.

2.4 Measuring accessibility

As a logical consequence of the manifold definitions regarding the concept of accessibility, there exists a wide range of different methods for measuring it. Several authors agree that there is no one single right way of measuring accessibility (Pirie 1979; Kwan 1998; Geurs & van Wee 2004), but rather, the suitability of the measures depends on the study context and on the phenomenon that is being analysed. In all, the selection of accessibility measures has a fundamental impact on the achieved results, and thus also on the possible policy consequences (Talen & Anselin 1998; Neutens et al. 2010). Hence, it is essential to recognise the implicit assumptions and limitations of the measures used in order to be able to evaluate the reliability and usability of the results (Pirie 1979; Geurs & van Wee 2004). Choosing the way in which accessibility is conceptualised and measured is not, therefore, a trivial task (Batty 2009).

Geurs & van Wee (2004) define four interrelated components of accessibility that can be used in evaluating the performance of different accessibility measures:

1. The *land-use component* describes the land-use, consisting of the spatial distribution of destination locations (i.e., activity sites that supply opportunities) and origin locations (where the demand for these opportunities comes from, e.g., inhabitants' homes) and the interaction between the two.
2. The *transportation component* describes the transport system and the effort that an individual has to take in order to overcome distance between origins and destinations, using a specific transport mode.
3. The *temporal component* describes the temporal constraints, such as an individual's time budget and the availability of different opportunities at different times of the day.
4. The *individual component* describes an individual's socio-economic and demographic characteristics (such as age, gender, income, education, physical condition, and

household characteristics) that affect his / her level of access to different transport modes and to the spatially distributed opportunities.

If an accessibility measure were to be perfectly sound theoretically, it should take into account all these components. Creating such a comprehensive indicator would, however, be very challenging (if not impossible) and the results would hardly be understandable or communicable to stakeholders – a requirement that is ranked high by many scholars (Handy & Niemeier 1997; Bertolini et al. 2005; Curtis & Scheurer 2010). Hence, in practice, accessibility measures often focus on one or more of these components (Geurs & van Wee 2004), and a combination of several complementary measures might provide a good solution to reveal several aspects of accessibility (e.g., Curtis & Scheurer 2010).

Many authors have presented useful reviews and classifications of different accessibility measures (e.g., Pirie 1979; Handy & Niemeier 1997; Geurs & Ritsema van Eck 2001; Geurs & van Wee 2004; Curtis & Scheurer 2010). At the coarsest level, different accessibility measures can be divided into *place-based measures* (describing how easily a certain place or location can be reached) and *person-based measures* (describing how easily an individual or a group of individuals can reach different activity sites) (see Pirie 1979; Kwan 1998; Hanson & Giuliano 2004; Neutens et al. 2010). Place-based measures (also called location-based measures) can be further classified into spatial separation measures (also called distance or connectivity measures) and potential accessibility measures (also called gravity measures) (Geurs & van Wee 2004). Person-based measures, in turn, are rooted in ideas of Hägerstrand's (1970) space-time geography; they measure accessibility from an individual's point of view, focusing on different spatial and temporal constraints for human activities (Kwan 1998; Weber 2003; Miller 2005; Shaw & Yu 2009). Since my focus is on the spatial separation measures, only these will be briefly reviewed here.

Although distance and time measures can be criticised for not incorporating several different components of accessibility (Geurs & van Wee 2004), the strength of these measures lies in the fact that they are intuitive, easy to understand and relatively undemanding of data. The simplest and most traditional form of distance measurement is the Euclidean distance between origin and destination (Ingram 1971). Since as-the-crow-fly distances fail to capture true patterns of human movement, the relevance of measures based on Euclidean geometry was questioned decades ago (e.g., Olsson 1965), and more functional conceptualizations of distance (such as network distance, time distance and cost distance) were brought into discussion (see Gatrell 1983). Travel time in particular is found to correspond relatively well to people's perceptions of accessibility (Olsson 1965; MacEachren 1980; Frank et al. 2008), although the notion of time undeniably is culturally constructed and thus differs between different parts of the world and between different individuals (see Banister 2011).

Developments in geographic information systems have greatly facilitated the computation of the more sophisticated spatial separation measures, such as network distances, different types of cost distances and travel times. Nowadays many standard GIS software provide tools for such calculations for different data models: cost distance algorithms for raster data, and network analysis tools (often based on Dijkstra's algorithm (Dijkstra 1959)) for vector data

(de Smith et al. 2009). The analysis scale and context determine what the most appropriate data models and tools to be used are. Cost distance algorithms are typically used when the movement is not tied to a predefined network but can occur anywhere in the landscape (e.g., Verburg et al. 2004; Jobe & White 2009), and network analysis tools – as the name suggests – are typically used in cases where the movement occurs along certain networks (e.g., Kumar et al. 2005; Neutens et al. 2010).

Typically, travel time based accessibility analyses are conducted from the car driver's perspective. Perhaps the most commonly used approach is to calculate travel times with network analysis tools by using road geometries (segment lengths) and speed limit-based estimates of driving speeds (e.g., Kumar et al. 2005; Neutens et al. 2010). The suitability of this approach is, however, a matter of scale and region. In broader scale analysis, speed limits may correspond relatively well to actual driving speeds, but novel approaches are needed for more detailed analysis of urban settings where free-flow travel times can be badly misleading. Congestion and parking add considerably to the real-life travel times that may end up being much longer than the ones calculated simply with speed limit information only (Christie & Fone 2003; Martin et al. 2008; Yiannakoulis et al. 2013).

A more detailed level approach is relevant also when the car travel times are intended to be comparable with other travel modes. After all, accessibility is not merely a matter of car travel, but it is essential to incorporate other locally relevant travel modes in the analysis.

Reasonable travel time calculations for public transport (PT) need to address slightly different things since public transport systems are more complex multimodal systems where different lines are bound to certain routes and schedules (see Kaplan et al. 2014). Typical simplifying assumptions in PT travel time calculations are constant travel speeds for each route (O'Sullivan et al. 2000; Liu & Zhu 2004; Peipins et al. 2011; Moniruzzaman & Páez 2012) and constant transfer times between different lines (O'Sullivan et al. 2000; Hess 2005; Peipins et al. 2011; Mavoa et al. 2012; Tribby & Zandbergen 2012). In addition, specific departure or arrival times are often ignored in PT analyses (see Lei & Church 2010).

Non-motorised travel modes are a special case, since the route choices of pedestrians and cyclists are not necessarily bound to transport networks, but rather include shortcuts not available for motorised traffic. Furthermore, the speed of movement of non-motorised modes is to a large degree determined by an individual's personal characteristics (Wu et al. 2010).

Naturally, the more detailed the scale of analysis, the more detailed and disaggregated data sources are needed (Geurs & van Wee 2004). Data for the typical car analyses (road geometries and attribute information on speed limits) are commonly available in many areas but data on the temporally varying congestion levels and parking space availability are much harder to obtain. GPS-based observations in the form of floating car measurements provide one potential data source for determining the congestion effects on travel times (e.g., Liu et al. 2013). For a long time, public transport analyses have lacked proper data models that would represent PT schedules in a standardised manner (see Lei & Church 2010). With the lack of appropriate schedule data – or proper (GIS-) tools for dealing with data that includes

temporal elements – PT travel time calculations have often been simplified as described above. Gradually the availability of standardised route and schedule data is increasing, and initiatives such as the OpenTripPlanner (OpenTripPlanner 2014) are distributing such data from different cities in a coordinated manner. One benefit of such data is that they are continuously updated and thus reflect the temporal variation in PT travel times during different times of the day and different seasons of the year.

Finally, the availability of network data for cycling and walking is typically much poorer than that for motorised transport (Kasemsuppakorn & Karimi 2013). Volunteered geographic information and recent crowdsourcing efforts, particularly OpenStreetMap (OSM), provide perhaps one of the most comprehensive and up-to-date data sources for identifying networks of cycling and walking (Zielstra & Hochmair 2011, 2012; Kasemsuppakorn & Karimi 2013). OpenStreetMap is to a large degree based on mobile data (see Mooney et al. 2012) and it is just one example of the potential that GPS-based mobility data provides for accessibility-related studies. In broader terms too, citizen science has become increasingly important for different (spatial) data considerations (e.g., Goodchild 2007).

3. STUDY AREAS

3.1 Contextual differences

This thesis is composed of case studies conducted in two very different environments: The Loreto region in the Peruvian Amazonia (I, II) and Greater Helsinki in Finland (III, IV, V) (Fig. 2). These two study areas are opposites in many aspects: Loreto is a vast rural region in the Global South and Greater Helsinki is a relatively small urban capital region in Northern Europe. In Loreto the transport network is fluvial and liable to natural dynamics whereas in Greater Helsinki the spatial arrangement of the road transportation system is a result of a fairly strictly regulated planning process. The temporal resolution of analysis is much coarser in Amazonia, where the focus is on region-wide mobility with several days' travel times, than in Helsinki where travelling from one end of the study area to the other only takes a couple of hours; consequently, the desired precision of the results is much looser in the Amazonian context, where travel time differences are analysed in days, than in Helsinki, where a minute or two in the results make a difference. Finally, the amount of readily available (transportation) data is much lower in Loreto than in Helsinki and the analyses are based on different types of data.

These clear contextual differences, of course, imply different methodological challenges for the case studies. Although some of the results are inherently unique to the specific study areas – and interesting precisely because of their uniqueness – the resulting understanding can in many ways be generalised to broader contexts too. Indeed, studying these two distinct regions makes it possible to draw broader conclusions on the topic of this thesis than what examination of one of these areas alone would have allowed.

3.2 Loreto region in the Peruvian Amazonia

Papers I and II examine accessibility in the Peruvian Amazonia. More precisely, paper I focuses on the whole Loreto region (largest of Peru's administrative regions, covering approximately an area equivalent to the size of Germany) and the analysis in paper II covers a smaller subset of the region (marked with a red rectangle, see Fig. 2).

Loreto provides an interesting case study setting for broad-scale accessibility analyses: While much of the past accessibility research has focused on road transport, the transportation network in Loreto is based on inland waterways (the mighty Amazon River with its numerous tributaries) and roads are still scarce. Ninety percent of the passenger and cargo traffic in Loreto occurs along the fluvial network (Ministerio de Transportes y Comunicaciones 2010). Different types of vessels ranging from large river launches to small boats with outboard motor provide transport between the riverine communities and Iquitos (the main market centre and the capital of the region) and other regional centres (Chibnik 1994) (Fig. 2). The lowland Amazonian rivers have very low gradients over long distances, which make them generally well suited for navigation (Hilling 1996). Indeed, this “natural transportation network” can be thought of as an ecosystem service provided by the rivers (see Guimaraes &

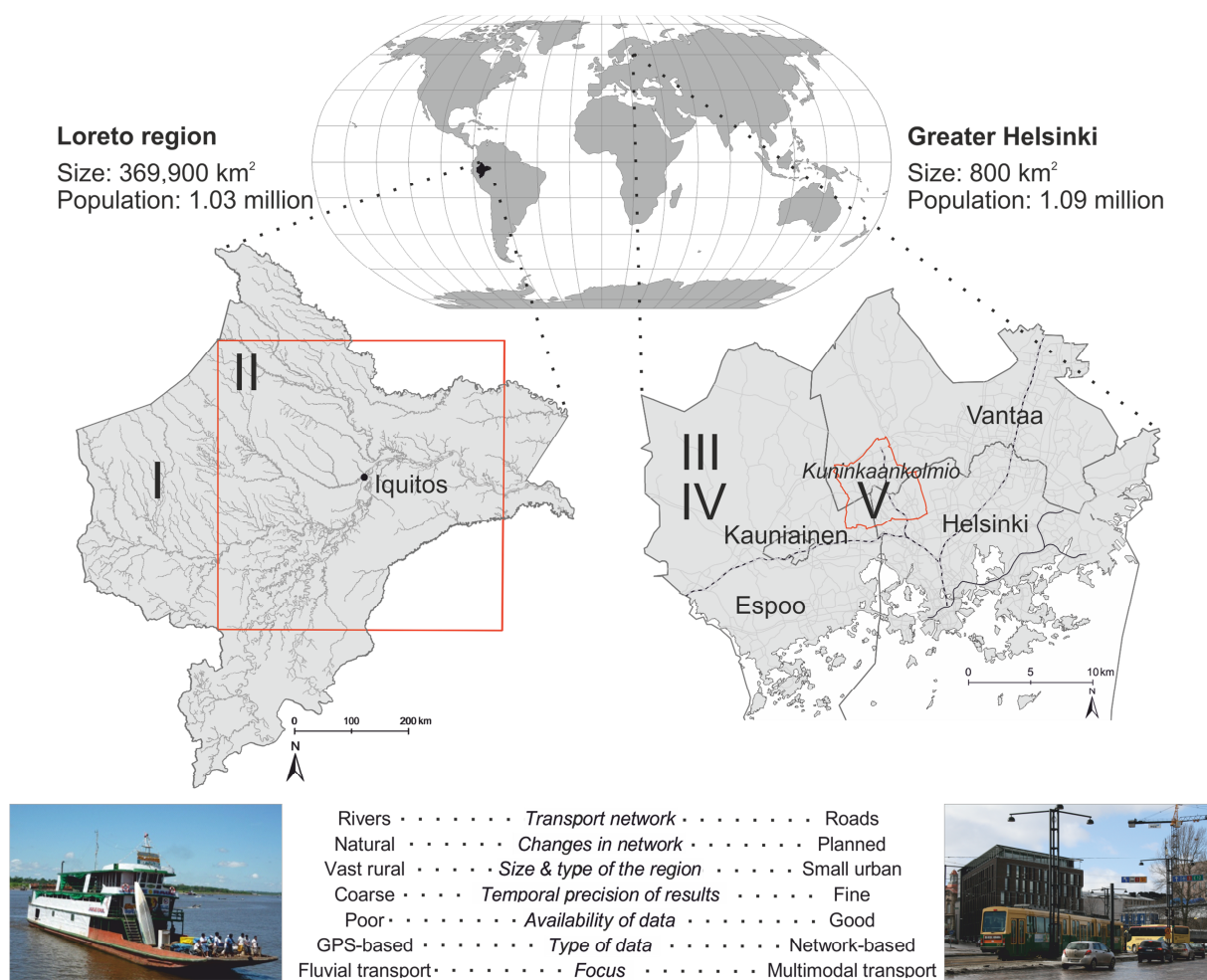


Figure 2. Case study areas: Location and crucial contextual differences. The roman numerals refer to the papers where the respective area is studied. More detailed maps of the study areas are presented in each paper. (Background map for Greater Helsinki © The City Survey Division of Helsinki, municipalities of Greater Helsinki, HSY, 01.01.2012; Background map for Loreto © GOREL 2008)

Uhl 1997), and at times of increasing concern over the sustainability of transport systems, water transport appears as a fairly ecological and relatively low-impact transport solution.

Yet, waterways are a challenging platform for transportation: irregularity, unpredictability and risk are always involved with fluvial transportation (Hilling 1996). Rivers are dynamic both seasonally and inter-annually, causing unpredictability in the form of water depths, sand bars and torrents. The pattern of the network is in constant change, owing to the high discharges, the thick loose sediment bed of the lowlands and tectonic activity of the Andean foreland (Sioli 1984; Puhakka et al. 1992). The lateral movement of the meandering river channels may be dramatic, at places even hundreds of metres a year (Kalliola et al. 1992). Weather anomalies caused by climate change further increase these natural risks (Marengo et al. 2008; 2011, 2012; Tomasella et al. 2013).

In Loreto – and in Amazonia in general – questions of accessibility are particularly important for environmental and human welfare related issues. The vast forest areas in Peruvian

Amazonia were previously considered nearly untouched due to their isolation from larger population centres (see Godfrey & Browder 1996), but now it is widely recognised that the area is facing continuously increasing land-use pressure caused by in-migration, expanding agricultural frontiers, intensified logging, and oil extraction (Nepstad et al. 2001; Barreto et al. 2006; Killeen 2007; Finer et al. 2008). Given the global significance of Amazonian forests for carbon sequestration and as a biodiversity hotspot (e.g., Fearnside & Laurance 2004), understanding spatial patterns of human impact and land-use pressure in the region is crucial. Here, understanding the spatial dynamics of accessibility is vital, since resource use and management decisions are in many ways affected by the relative locations of population and resources and transport options between them.

Physical accessibility is also crucial for human livelihoods, social interaction, education opportunities, and health care of the Amazonian rural population. Many rural dwellers face difficulties in earning their living due to lacking transport facilities and poor accessibility to the regional centres (Padoch et al. 1985; Shanley et al. 2002). For many riverside communities in Loreto, the production and sale of agricultural and non-timber forest products (NTFPs) are the only sources of employment and monetary income (Padoch & De Jong 1990; Pyhälä et al. 2006). Transportation is especially critical for the trade of perishable products, such as fresh fish or moriche palm fruits. Problems in the logistic chain, including the irregularity and unpredictability of transportation can lead to considerable spoiling and losses of commercially valuable products, and thus, waste of nutrients and lack of income (Hilling 1996).

3.3 Greater Helsinki in Finland

Papers III, IV and V focus on the capital region of Finland. The analyses in papers III and IV deal with all of Greater Helsinki and paper V focuses on a subset of Greater Helsinki (the *Kuninkaankolmio* area, marked with red in Fig. 2).

The good availability of transport related data makes Greater Helsinki an interesting case study site for urban accessibility research. Several open data sources enable a detailed analysis of different urban travel modes, in addition to the traditionally analysed private car, and make Greater Helsinki an ideal methodological test bed for multimodal travel time analyses. Accessibility questions are particularly topical in the area now that the city of Helsinki is working on a new city plan, based on ideas of a rail-based network city and sustainable mobility (City Planning Department of Helsinki 2013).

Residents in Greater Helsinki travel typically by car (39 % of daily trips), public transport (26%) and non-motorised travel modes (33 %) (HRT 2010). Recently, for the first time in the past 50 years, the share of public transport has been growing (HRT 2012). The road network relies on a few large ring roads (west-east) and several radial roads originating from the city centre of Helsinki. The public transport system of Greater Helsinki is composed of an extensive bus network and a few railway lines (north, northwest and west of the city centre), complemented by metro (currently operating in Eastern Helsinki; in the future, also in western parts of the region), and trams and ferries within the municipality of Helsinki.

Overall, the current structure of the public transport network is highly city centre oriented and crosstown connections are one of the key development areas in future public transport investments (see Salonen et al. 2012). Despite the poor crosstown connections, residents in Greater Helsinki are rather satisfied with their public transport system, at least when compared to other European cities (European Commission 2010; HRT 2012).

Greater Helsinki is a good example of a relatively small metropolitan area where accessibility questions are interwoven with changes in the urban structure, and with concerns over the sustainability of urban transportation and residents' daily mobility. As many other urban regions world-wide, Greater Helsinki is facing a challenge of sprawling urban fabric (EEA 2006; Schulman & Jaakola 2009). Since the 1950s the population in the metropolitan area has grown tremendously and the region has gone through a structural change in form of suburbanisation (Vaattovaara 2011). Gradually, the region is becoming more polycentric (Joutsiniemi 2010; Vaattovaara 2011), but so far the Helsinki city centre remains clearly the strongest centre with highest population and job densities (Vasanen 2012). An increasing population naturally means also more transport, and the changes in the urban structure are reflected in residents' daily mobility. A key challenge for the future of the region is thus to increase the share of sustainable travel modes and particularly to promote cycling and walking (HRT 2013).

4. MATERIALS AND METHODS

4.1 Study design

The study design of this thesis can be described as a PPDAC-process, which is a conceptualisation and framework applicable for any spatial analysis process (de Smith et al. 2009). The PPDAC process consists of five inter-related (and partly iterative) steps: (1) **Problem framing**; (2) **Planning and formulating the approach**; (3) **Data acquisition**; (4) **Analysis**; and (5) drawing **Conclusions** (Fig. 3).

The research problems (Step 1, presented in the Introduction chapter) are approached through five case studies (Step 2, general level planning), and plans for each individual case study are presented in the respective papers (Step 2, detailed planning). While detailed descriptions of data sources and methods are found in the respective papers, the following sections will give a general view on the types of data (Step 3, Data acquisition) and the methods and tools that I used in the different case studies (Step 4, Analytical methods and tools). In all, I applied combinations of different types of data sources and several methodological approaches in order to answer the study questions in a comprehensive manner. The results and conclusions (Step 5, presented in each paper and in Chapter 5 of this thesis) have partly served as input for framing and specifying new research problems.

4.2 Data acquisition

4.2.1 Transportation data

I am using several transport-related data sources: most importantly, **GPS-based direct observations** and different types of **network and schedule data**. The GPS-based observations are used as a primary data source in papers I, II (and as a secondary data source also in papers III, IV and V) and the network and schedule data are used in papers III, IV and V.

GPS-data for papers I and II were gathered aboard riverboats along major rivers in Loreto in 2009. In practice, I measured navigation speeds along the region's most important navigation routes and in the vicinity of the city of Iquitos. These observations were later generalised for the whole river network of Loreto and used for creating the time distance surface in paper I.

In car analyses (III, IV, V), a modified version of the national road and street database Digiroad was the basis for the analyses¹. Digiroad contains a detailed topological representation of all roads and streets in Finland and attribute information, such as speed limits and classifications for each road segment. The database is updated on a regular basis by the Finnish Transport Agency and it is probably the most widely used data source for routing analyses in Finland. The speed limit-based routing impedance values of Digiroad were adjusted to better fit the real-life driving times in the case study area (Jaakkola 2013). This

¹ *The modified version of Digiroad – called MetropAccess-Digiroad – is freely available at <http://blogs.helsinki.fi/saavutettavuus/data/metropaccess-digiroad/>*

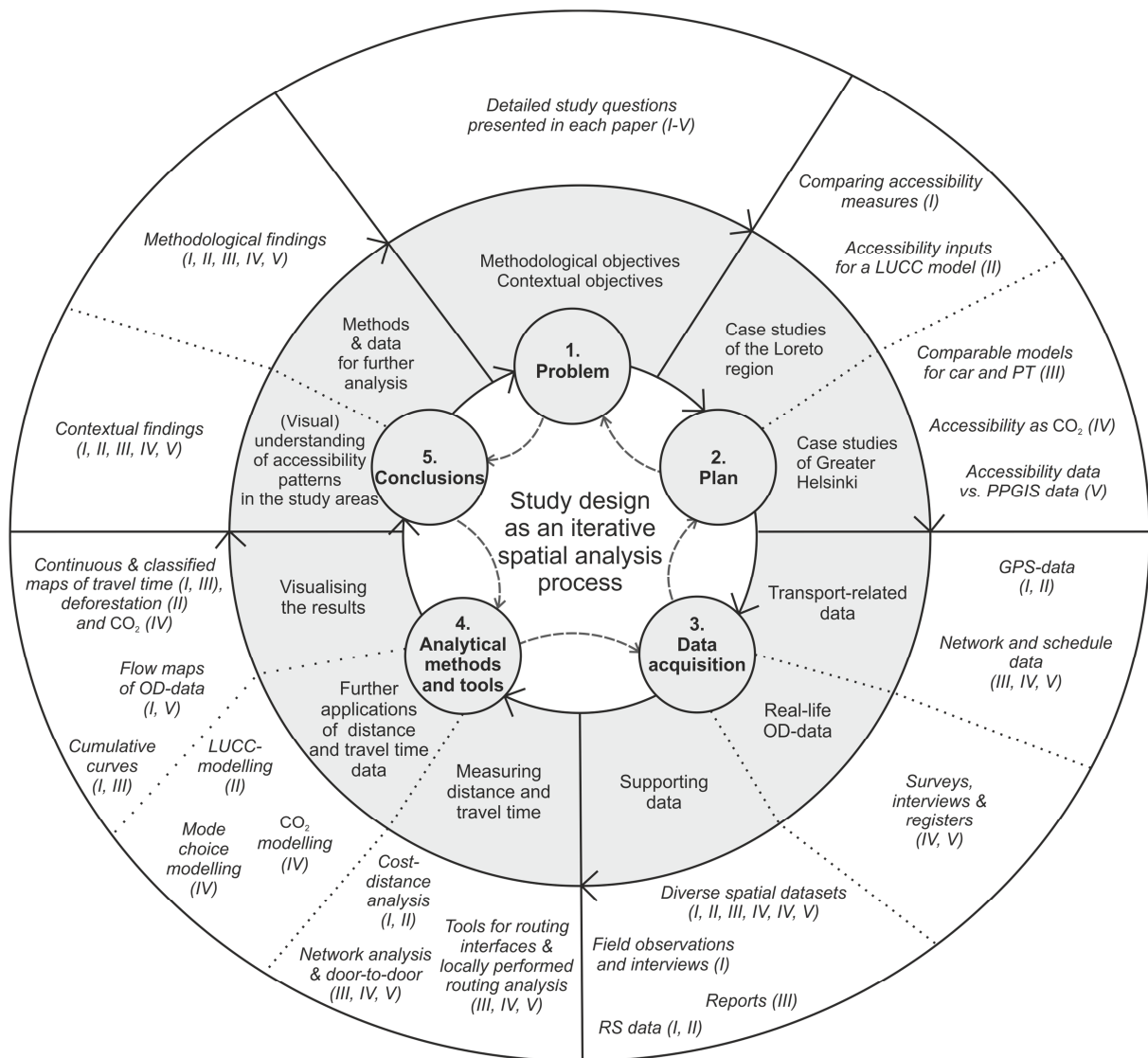


Figure 3. Study design as a PPDAC-process. Realisation of the process at the thesis level (inner, light grey circle) and at the level of the individual papers (outer, white circle).

was done by assigning different deceleration values for cross roads belonging to different road classes (cf. Thériault et al. 1999; Määttä-Juntunen et al. 2011; Yiannakoulias et al. 2013). The deceleration values were derived from floating car measurements (gathered by Helsinki Region Transport and the City Planning Office of Helsinki) where real travel speeds along different roads of the study area were measured with GPS during normal weekdays at different times of the day. Finally, the effect of functional road classes and crossroads on travel speeds was formulated to deceleration values by means of a regression analysis, as follows: Crossroads on road classes 1 and 2 (regional main roads / streets) got a daily average deceleration value of 11.31 s; crossroads on road class 3 (local main streets / regional roads) got 9.44 s; and crossroads on road classes 4–6 (collector streets / connecting roads, feeder streets and private roads) got 9.36 s. The directionality of congestion was not taken into account. (See paper III and Jaakkola (2013) for more details).

Openly available public transport route and schedule data of Helsinki Region Transport's Journey Planner service (HRT 2014) were the most important data sources in the public

transport analyses (III, IV, V). In our study area these data can be regarded reliable, given that the different PT travel modes follow their schedules relatively strictly (HRT 2012). In paper III, also PT route geometries (produced by HRT) and web-based schedule information were used for an alternative travel time modelling approach. As part of the PT analyses, data for the pedestrian network was either incorporated in Journey Planner's databases (III and IV) or this information was retrieved from OpenStreetMap (V).

4.2.2 Real-life origin-destination (OD) data

Data that reveals residents' realised travel patterns (origins and destinations of daily mobility) were an important counterpart for the theoretical routes obtained through the travel time analysis. In paper IV, library customers' travel patterns were estimated from a **Library Loan Database** (LLDB) provided by the libraries in the Helsinki region (Helmet-libraries). This dataset is a one-day snapshot of all library items that were out on loan on a certain date (November 15, 2011) (418,293 loans made by 104,661 customers). The dataset contains anonymous information on the customer's home address and on the library where the loaned item belongs. Based on these data, the origin (customer's home) and the destination (library) of each library trip could be determined and an OD-matrix created.

Paper IV also utilised a **library customer survey** (n=584) that was conducted in all public libraries within Helsinki during October-November 2011. As part of the survey, each respondent reported his / her home location on a 250-m grid cell accuracy and the travel mode(s) he / she used. Based on these answers and the place of the interview, we could construct an OD-matrix describing the real-life library journeys.

In paper V, the origins and destinations of daily mobility analysis were defined based on **softGIS data** which was gathered as part of the Everyday Urbanity project at the Aalto University, using public participation GIS (PPGIS) methods. In the internet-based survey, residents (n=711) of the Kuninkaankolmio region (Fig. 2) reported their daily mobility patterns (homes considered as origins and regularly visited places as destinations), including the travel modes that they typically use on each trip.

4.2.3 Supporting data

A variety of other data sources were used to complement the above mentioned ones. In the Peruvian case studies, **semi-structured interviews** related to the frequency of boat traffic, the capacity of boats, and the principal market products were conducted with boat operators and other stakeholders involved in the river trading process in the ports and markets of Iquitos. **Field observation and documentation** during later field work phases also helped to understand the prevailing transport realities in the region. Secondary data for papers I and II consisted of **diverse spatial datasets** (describing the structure of the river network, different classifications of the rivers and the landscape in general, land tenure and deforestation patterns) and **remotely sensed (RS) data** (a mosaic of Landsat TM satellite images and SRTM data). These datasets were gathered from a multitude of sources, as specified in the respective papers (I, II).

In papers III and IV, **population data** from SeutuCD 2009 (YTV 2009) was an essential component of the analyses, defining the origins of routing analyses. The original data was at building-level but for the analyses it was aggregated to 250 m grid cells. With the lack of detailed spatial and empirical data, a few **research reports on parking conditions** (Kurri & Laakso 2002; Kalenoja & Häyrynen 2003) were needed for defining the necessary values for car travel time calculations in Greater Helsinki. Finally, the openly available Seutukartta 2012 (HSY 2012) provided the necessary data layers for **visualisations**.

4.3 Analytical methods and tools

4.3.1 Measuring distance and travel time

In paper I (and II), accessibility was quantified as four types of distances: Euclidean distance to the centre, Euclidean distance to the river network, network distance to the centre and time distance to the centre. The *Euclidean distance* from each raster cell to the city of Iquitos and Euclidean distance from each raster cell to the closest river / road network cell were calculated based on coordinates in WGS84 / UTM zone 18S (EPSG:32718). The *network distance* from each raster cell to the city of Iquitos along the river network and *time distance* from each raster cell to the city of Iquitos were calculated using cost distance tools in ArcGIS 9.3.1 (ESRI, Redlands, CA, USA). Although network-based distances typically are calculated with network analysis, I decided to employ the cost surface method in order to take into account movement across land areas also.

In order to support and complement the analysis of accessibility as metres and minutes, paper I also quantified boat frequencies and their carrying capacities based on interviews with Amazonian boat operators. This type of information is necessary to complement the purely distance or time-based measures particularly in an environment where transport connections are sparse and capacities critical.

In papers III, IV, and V the analyses were based on networks of the different urban travel modes. In these cases, I applied tools of network analysis, partly using the Network Analyst extension in ArcGIS 10 (car analyses in papers III, IV and V), partly relying on open routing interfaces (PT and walking / cycling analyses in papers III and IV) and partly using routing tools developed as part of our research project (PT and walking / cycling analyses in paper V) (see section 4.3.1.2). Common for all these approaches is that they rely on shortest path algorithms, developed from Dijkstra's original algorithm (Dijkstra 1959).

4.3.1.1 Door-to-door approach in urban travel time calculations

In order to ensure the comparability of the different urban travel modes (car, public transport, non-motorised modes) paper III introduces the concept of *door-to-door approach* for travel time calculations (cf. Liu & Zhu 2004; Lei & Church 2010; Benenson et al. 2011). In practice, this approach means that every stage of a journey between its origin and destination are taken into account when calculating travel times and distances. By car, a door-to-door journey includes (1) walking from the point of origin to the place where the car is parked; (2) driving from the parking space to near the destination; (3) looking for a parking space near the

destination; and finally, (4) walking from the parking space to the destination itself. Given that public transport is bound to predefined routes and schedules, a door-to-door PT journey may be slightly more complicated. The basic parts include (1) walking from the point of origin to the appropriate stop (access time); (2) waiting for the transport vehicle to arrive and to depart; (3) sitting in the vehicle between the initial and final stops; and (4) walking from the last stop to the final destination (egress time). In addition, many public transport journeys include transfers from one route to another, which possibly imply walking from one stop to another and waiting for the next vehicle to depart.

4.3.1.2 Computational tools

The Journey Planner's route and schedule data were used in two different ways: In papers III and IV, the routing analyses were done through an open API (application programming interface)², and the tools for utilising the API were developed by our research group³ (see Jäppinen et al. 2013). Due to limited service capacity on HRT's servers and resulting query restrictions and hindrances in the analysis speed, the routing analyses in paper V were done locally on our own servers. In collaboration with BusFaster Ltd., we developed tools (MetropAccess-Reititin⁴) to utilise the Journey Planner data in Kalkati.net format (a data dump XML file which includes the route and schedule data in a single file) (Järvi et al. 2014). The Kalkati-data does not contain information about the pedestrian network and hence, MetropAccess-Reititin utilises OpenStreetMap to define pedestrian connection to and from the PT network. The OSM data was deemed the most appropriate, after assessing the completeness and quality of a few other data sources containing data on the pedestrian network. In comparison to utilising the Journey Planner data through the API, the analysis with MetropAccess-Reititin was faster and certain parameters could be more flexibly and transparently adjusted. In both cases, the route search parameters such as walking speed, preferred means of transport, transfer time margin and penalty for additional transfers could be adjusted.

4.3.2 Further applications of distance and travel time models

The iterative nature of the PPDAC process (Fig. 3) becomes particularly visible in how the final results of paper I and III were further processed in papers II, IV and V. The different distance surfaces of paper I were used as inputs for a land-use and land cover change model in paper II. In a similar fashion, the ideas of the most advanced public transport and car models presented in paper III were used for mode choice modelling and CO₂ calculations in paper IV and for defining the fastest mode choices for residents' daily travel routes in paper V.

² *The Journey Planner API, provided by Helsinki Regional Transport Authority (HRT), is provided for applications and services that support public transport usage and transport information availability. Use of the interface and the data is free of charge but requires registration. The data and API documentation are available at <http://developer.reittiopas.fi/pages/en/home.php>*

³ *The source codes for the API query tools are available at Github <https://github.com/matti/reittihaku>*

⁴ *The source code for MetropAccess-Reititin is available at <http://blogs.helsinki.fi/saavutettavuus/tyokaluja/metropaccess-reititin/>*

4.3.2.1 Land-use and land cover change (LUCC) modelling

In paper II, the different distance surfaces from paper I were tested as explanatory variables in a LUCC model that replicated deforestation patterns in Loreto. Out of a few possible LUCC modelling platforms, Dinamica EGO (version 1.6.2) was used (Soares-Filho et al. 2009). This cellular automata modelling platform was initially developed for LUCC modelling in the Amazon region, and since its development, it has been widely used to model land change processes in different parts of the world (Maeda et al. 2010, 2011; Fuller et al. 2011; Thapa & Murayama 2011).

The model received three datasets as inputs:

- (1) an “initial landscape map” describing the land cover at the beginning of the modelling period (including classes of forest, non-forest and floodplain);
- (2) a “final landscape map” describing the actual deforestation pattern at the end of the modelling period (again, including classes of forest, non-forest and floodplain); and
- (3) a set of explanatory variables, including: (1) an accessibility surface (different for each simulation); (2) a digital elevation model; (3) a map of geological formations; (4) a map of protected areas; and (5) a map of indigenous territories. As our focus was on the accessibility measures, we did not analyse the role of the different landscape variables separately but used these variables as one group.

As outputs the model produced simulated landscape maps representing the predicted configuration of land cover classes (forest, non-forest and floodplain) in the landscape.

The LUCC simulation process had four steps. First, the amount of land change from one land cover class to another was estimated by comparing a hypothetical “zero-deforestation” situation (“initial landscape”) to the amount of deforestation in the year 2000 (“final landscape”). This was the amount of deforestation to be allocated in later phases. Second, the probability of change in each pixel was assessed based on the explanatory variables. Third, the land change pixels were stochastically allocated in iterative steps. Finally, the model performance was assessed with fuzzy similarity index (Almeida et al. 2008; Soares-Filho et al. 2009) that compares the simulated landscape maps with the observed deforestation pattern at different levels of detail.

4.3.2.2 CO₂ calculations and mode choice modelling

Paper IV approached accessibility through carbon dioxide (CO₂) measures. First, the library customer survey was used to build a mode choice model that was later applied to the entire library loan database to determine library customers’ most probable mode of travel on their library trips. The modelling exercise was based on multinomial logistic regression which, despite criticism for its simplifying assumptions, is widely used in mode choice modelling (e.g., Schwanen et al. 2001; Domarchi et al. 2008; McDonald 2008; Müller et al. 2008). The modelling was performed in R, using the *mlogit* package, with the following variables: The independent variable was the travel mode represented by three categories (non-motorised transport [i.e., walking / cycling]; public transport; car). Explanatory variables were trip length, respondents’ age and gender, and the urban zone classification (Ristimäki et al. 2011) of the respondent’s home. The model was built with so few variables because of the limited

information stored in the LLDB. It is, however, important to note that an individual's socio-economic background and different attitudinal and psychological factors have also been proven to be efficient explanatory variables in mode choice models (Van Wee et al. 2002; Domarchi et al. 2008; Eluru et al. 2012).

Finally, using the average CO₂ emissions of different types of vehicles (<http://lipasto.vtt.fi/index.htm>) and a detailed description of each library route (including information on the modelled travel mode and on how many metres were travelled using each travel mode) we approximated the CO₂ emissions resulting from each library trip.

4.3.3 Visualising the results

Visualising the results in a meaningful way is an important step in any spatial analysis (Rodrigue et al. 2006), and not least accessibility analyses (Curtis & Scheurer 2010). In this thesis too, the most essential contextual findings were presented in map form (I, II, III, IV, V):

Continuous raster surfaces and classified grid cells were used to visualise travel times (I, III), deforestation patterns (II) and CO₂ values (IV). *Flow maps* were used to visualise different types of origin-destination (OD) data: capacities and frequencies of river boats (I) and the suburban residents' daily mobility patterns (V). In addition to the spatial representations, papers I and III show cumulative curves where the cumulative share of area (I) and population (III) is visualised as a function of distance (I) and travel time (I, III).

5 RESULTS AND DISCUSSION

5.1 Methodological findings

5.1.1 Realistic accessibility analyses require consideration of different travel modes and regionally specific transport network properties

Examples from my study areas demonstrate how both in rural and urban contexts the selection of accessibility measures greatly impacts our impression of the spatial variation of accessibility (I, III). The consideration of locally relevant travel modes is important, and the regionally specific transport network properties affect the ways in which distances and travel times need to be quantified.

In fluvial transport systems, such as the one in Peruvian Amazonia, travel speeds vary considerably by direction of movement (upstream vs. downstream), by channel type and by the type of vessel (I). Furthermore, there are large seasonal differences in travel speeds since water level fluctuations affect the navigability of rivers (Chibnik 1994; Kvist et al. 2001; Tenkanen et al. 2014). Although travel times and metric distances measured along the river network are highly correlated in Loreto, travel time measures are clearly more sensitive to changes in river channel characteristics; narrow meandering channels require slower navigation speeds (and different types of vessels) than larger channels that are straighter in shape (I). Empirical data on navigation speeds (I) combined with relevant river type classifications would enable the extrapolation of the travel time models to larger areas in Amazonia.

In urban settings, such as in Greater Helsinki, accessibility analyses need to take into account several available travel modes and their specialties. More fine scale analysis of car accessibility and the incorporation of the more sustainable travel modes are particularly topical now, given the growing concerns over the environmental and social sustainability of urban transport (e.g., Banister 2008; Jacques et al. 2013). This thesis challenges the traditional car-based approach to accessibility analysis and shows how some commonly encountered simplifications in distance and travel time calculations by car and public transport can be avoided.

In order to take into account the different factors affecting real-life travel times by car, paper III utilises a method that assigns empirically defined deceleration values to cross roads, thus making more realistic assumptions of driving speeds in the study area. Furthermore, the calculation included the time needed for parking the car, which constitutes a significant addition to in-vehicle travel time. The results show that car travel times in Greater Helsinki are over twice as long if congestion and parking (the door-to-door approach) are taken into account in the calculations, in comparison to purely speed limit-based travel time estimates (III).

For public transport travel time analyses, paper III presents an approach that is based on detailed PT route and schedule databases. These data sources make it possible to model

realistic public transport routes, including scheduled departure / arrival times and realistic transfer and access / egress times. Our analysis shows that the door-to-door approach in PT travel time calculations produces on average nearly 70% longer travel times than a calculation method where constant travel speeds and regular transfer times are assumed (III). The door-to-door approach combined with the increasing availability of standardises PT route and schedule information from different city regions around the world (e.g., Google Transit Trip Planner 2014; OpenTripPlanner 2014) would also allow international comparisons of public transport accessibility patterns.

The door-to-door approach not only makes the results of travel time analysis more realistic for each travel mode per se but it also provides a practical solution to the comparability of different travel modes; when all parts of the journey are taken into account in calculations, the methods of calculation are conceptually corresponding among the different travel modes (III). This is important to take into account if we wish to use the modal accessibility disparity as an indicator of the equity of the different travel modes and of the auto-orientation of the urban structure (cf. Martin et al. 2002; Kawabata 2003, 2009). Modal comparison based on conceptually different models may result in unrealistically large (or small) modal travel time differences and thus the results of the analysis become questionable. The use of inappropriate methods also makes it difficult to draw broader conclusions about the equity of travel modes in the respective study area in comparison to other city regions (III).

***To conclude:** Travel time calculations are highly sensitive to regional characteristics of the transport networks and the inclusion of locally relevant travel modes is a prerequisite for realistic accessibility analysis. In fluvial transport networks (exemplified by the Loreto case studies) travel time analysis is sensitive to river channel types, direction of movement, and seasonality. In urban settings (exemplified by case studies in Greater Helsinki) the door-to-door approach for urban multimodal travel time calculations makes the analysis more detailed and gives more realistic results than calculation of in-vehicle travel times only. The door-to-door approach also makes different urban travel modes mutually comparable.*

5.1.2 The significance of the more realistic quantification methods is highlighted in further applications

The results of spatial analysis are only as good as the underlying components of the analysis allow. This becomes particularly visible in examples provided by papers II, IV and V where the methods developed in papers I and III are applied.

Data quality is fundamental for the success of LUCC modelling efforts, and despite the increasing availability of data, the selection of suitable variables for simulation models is challenging (Veldkamp & Lambin 2001; Verburg et al. 2011b). Paper II shows how the results of an Amazonian deforestation model vary based on the different accessibility measures that the model receives as inputs. Out of the individual accessibility measures, the most advanced one – travel time to market centre – works best as accessibility input for the model. The most accurate simulation is achieved when travel time to a market centre is used in association with distance to a transport network and additional landscape variables. Results

of paper II suggest that if more sophisticated accessibility measures are used instead of the more traditionally employed simple Euclidean distance measures, the LUCC models' spatial accuracy – which often remains low (Pontius et al. 2008) – could potentially improve.

Another example of the usefulness of advanced calculation methods is provided in paper IV. There, the door-to-door travel chains are used to create an additional measure of accessibility, namely, CO₂ load for each library trip. Owing to the concern over urban transport's role in climate change, the inclusion of CO₂ measures has become more common in accessibility evaluations (e.g., Wood 2003; Winebrake et al. 2008; Määttä-Juntunen et al. 2011). Although the way in which the CO₂ values are estimated is a fairly coarse approximation (ignoring, for example, the age, life cycle and energy sources of vehicles (see EEA 2014)), the detailed measures of distances (provided by the door-to-door approach) and locally adjusted estimates of the average CO₂ emissions per vehicle kilometre travelled do provide us a reasonable view of the general pattern of possible emissions.

The value of advanced quantification methods also becomes visible in paper V where the Kuninkaankolmio residents' survey answers are complemented with the computational travel time information. As previous research has shown, survey respondents have difficulties in estimating travel times and distances in a reliable manner (Murakami & Wagner 1999; Macintyre et al. 2008). If distances and travel times are to be used as explanatory variables in analysis, it becomes problematic if the data related to these variables are badly skewed. Advanced methods for calculating distances and travel times between the survey-revealed origins and destinations make it possible to determine these variables objectively (V).

***To conclude:** The value of the more advanced quantification methods becomes truly visible when the results obtained from the accessibility calculations are further applied in new analyses. This thesis shows how poorly selected measures of accessibility may lead to inaccurate LUCC modelling results, and vice versa, how more sophisticated measures may improve the overall accuracy of such models. In the urban context, detailed travel chain descriptions (door-to-door approach) together with data on travel mode-specific average CO₂ emission levels enable us to make a general assessment of carbon emissions resulting from urban travel. Furthermore, the advanced calculation methods provide an objective way to estimate travel times and distances, which can be used to complement survey respondents' self-reported mobility patterns.*

5.1.3 Euclidean distances may work as accessibility surrogates but need to be used with caution

As the examples from the previous chapters show, using advanced ways of calculating distance and travel time has clear benefits. Nevertheless, low data requirements and easy, often readily available calculation methods make also the use of Euclidean distance as a measure of accessibility appealing (see Ingram 1971; Shadid et al. 2009). Although the limitations of these simple distance measures are widely acknowledged (e.g., Olsson 1965; Ingram 1971; Nelson & Hellerstein 1997; Apparicio et al. 2008; Gutiérrez & Garcia-Palomares 2008; Shadid et al. 2009; Verburg et al. 2004; 2011a; Moseley et al. 2013),

Euclidean measures are fairly commonly used in different urban planning tasks (see Gutiérrez & Garcia-Palomares 2008; Moseley et al. 2013) and LUCC models (Laurance et al. 2002; Chomitz & Thomas 2003; Mas et al. 2004; Viña et al. 2004; Jasinski et al. 2005; Kirby et al. 2006; Soares-Filho et al. 2006; Pan et al. 2007; Kim 2010; Thapa & Murayama 2011). As Boscoe et al. (2012) demonstrate, Euclidean measures might actually provide a reasonable approximation of travel times when the scale of analysis is coarse enough and when the networks of movement are evenly distributed.

My case studies provide mixed evidence about the usefulness of Euclidean measures as accessibility surrogates. In an environment like Loreto, where the overall connectedness of the transport network is fairly poor, the travel speed varies greatly by the direction of movement, and where most navigable channels are meandering, Euclidean distances between the rural communities and the regional centre are drastically different from real-life travel distances and times (I, II). Indeed, in Loreto the correlation between Euclidean distances and travel times and network distances is very poor ($r \approx 0.14$; $p < 0.01$; and $r \approx 0.26$; $p < 0.01$, respectively) (I).

Despite the poor correlation between the Euclidean measures and the more advanced distance measures, paper II shows that the combination of a few complementary Euclidean measures (distance to regional centre and distance to the closest river network element) can actually provide a reasonable surrogate for regional-level accessibility (or human influence), to be used in a LUCC model. The spatial accuracy of results from a model with the combination of these Euclidean measures was nearly as good as the accuracy of a model where time distance to centre was used as accessibility surrogate. On the contrary, when the Euclidean measures were used separately from each other, their performance as LUCC model input was much poorer than the performance of travel time and network distance measures. Here, it is essential to note that the phenomenon analysed (deforestation) is not sensitive to travel time in the same way as the transport of perishable products is, for example (I). In all, the results of the LUCC modelling exercise suggested that if proper data for more sophisticated analysis are lacking, the use of Euclidean measures can be justified – but needs to be done with consideration.

In Greater Helsinki the road network is fairly extensive and evenly distributed. Correlations between Euclidean distances and real-life distances and travel times by car are rather high ($r > 0.9$, $p < 0.01$) – Euclidean distances being around 30% shorter than trip distances along the road network (III). Given that the public transport network is considerably sparser than the network for car drivers, the difference between Euclidean distances and network distances is naturally bigger; Euclidean distances account for up to 62% of public transport trip distances. Furthermore, the correlation between Euclidean distances and travel times by public transport is considerably poorer ($r=0.830$) in comparison to correlation with car travel times ($r=0.913$) (III).

To conclude: *The suitability of Euclidean distances for accessibility studies is a highly scale-dependent matter and depends on the travel mode and type of transport network that is being analysed. The use of Euclidean distances instead of the more advanced distance*

measures can be justified – or even reasonable – in situations where appropriate data for calculating more advanced accessibility metrics is lacking. Knowing the limitations of these measures, however, is important when applying them. When modelling deforestation in Amazonia, the combined use of a few different Euclidean measures provided a fair estimate of the effect of accessibility for the spatial distribution of land changes. However, Euclidean measures correlated particularly poorly with travel times in Amazonia and with public transport travel times in Greater Helsinki. Thus, to be on the safe side, using more sophisticated calculation methods is advisable whenever there is sufficient data for doing so.

5.1.4 Combination of diverse data sources support advanced accessibility analysis

This thesis provides examples of how diverse data sources and their innovative combinations can be used in accessibility analyses. As in any analysis, the more advanced the methods for accessibility modelling are, the more data hungry they tend to be (I, III) (see also Geurs & van Wee 2004). Open data policies among different data producers can considerably facilitate fine-scale accessibility analyses by ensuring the availability of good-quality data (cf. McLaren & Waters 2011; Jetzek 2013; Jäppinen et al. 2013). Greater Helsinki provided a good example of this: many spatially referenced and up-to-date data sources, collected with high level of detail (e.g., the Digiroad and JourneyPlanner data) are open and freely available. This makes it possible to model multimodal travel times in a much more realistic way than what poorer data sources have allowed (III). The Peruvian case studies, on the other hand, provided a data-wise different setting for accessibility studies; data on river boat movements hardly exist in electronic and coordinated form, and thus, gathering the necessary information on-site was the only option (I).

The computational accessibility models are interesting as such but they become particularly useful when combined with data that reveals residents' true patterns of daily mobility. In this thesis, the library loan database (IV) and the softGIS data (V) provided such information. A combination of these two types of data reveals in an interesting way how residents' real-life mobility patterns differ from the computationally "optimal" patterns (IV, V). Indeed, identifying discrepancies between the optimal and true patterns of mobility could serve as a tool to identify the key areas for local policy intervention when daily services and transport infrastructure are planned or reorganised.

Based on the LLDB and the softGIS data, the residents' home locations were used as origins in travel time calculations (IV, V). While the home-location is often the best surrogate for the location of the population (data on home locations are commonly available), in reality, it effectively describes the population's night time location, which in many cases is drastically different from the daytime spatial distribution of people. Although many of the daily trips in Greater Helsinki do indeed start or end at home (Ratvio 2012), recent findings on trip chaining (Næss 2006; Haugen & Vilhelmson 2013) suggest that trips made for different purposes are often chained, and thus, it would be wrong to assume all trips start from home.

Mobility data mining, i.e., collection and extraction of knowledge from mobility data (such as mobile phone records or social media data), provides one possible, interesting and novel way

of identifying people's daytime locations. The ubiquitous mobile devices and the role of citizens as data producers are likely to grow tremendously in the near future, making the analysis of big data both a promising and a challenging new direction of research (Goodchild 2007; Batty 2012). Although concerns over the privacy of individuals have partly impeded the use of mobile data, recent research efforts (Giannotti & Pedreschi 2008; Abedi et al. 2014) and movements such as MyData (OKFN 2013) have proven successful in developing guidelines for maintaining individuals' privacy in such data. Mobile data are already actively being used for studying the spatio-temporal dynamics of human movements (e.g., Ahas et al. 2008, 2010; Kang et al. 2010; Abedi et al. 2014; Pentland 2014), and their value for transport and urban planning applications is recognised (Giannotti & Pedreschi 2008; Batty 2010, 2012). The spatial and temporal resolution of such data provides completely new opportunities for future studies of daily mobility and accessibility (see Batty 2012). Future accessibility analyses can potentially be performed to an increasing degree based on (real-time) data on true mobility patterns instead of static network data.

Just as the above discussed mobility data in urban applications would allow us to detect “the pulse of the city” (Batty 2010), longer-term GPS-based monitoring data on river boat movements would help us to assess the temporal dynamics of Amazonian river transports. Now the GPS data underlying Loreto's travel time model (I, II) were from a single time period, and thus gave a static view on travel times in the region. However, like tropical rivers in general (Hilling 1996), the Amazonian river network is highly dynamic and the navigability of the channels vary greatly over time, both seasonally and annually (Kvist et al. 2001; Marengo et al. 2008). Longer-term monitoring data, combined with climate data over respective periods (see Espinoza et al. 2013), would possibly allow us to analyse the climate change induced changes in accessibility patterns – a topic that is likely to become very topical particularly for near-natural transport networks when extreme climatic events are becoming more common (see Szépszó et al. 2014; Marengo et al. 2008). Although GPS-based monitoring systems are a commonplace in maritime transport (the AIS system, see Cairns (2005)), corresponding systems for Amazonian vessels are still in the development stage. Our preliminary results based on data from a pilot GPS-monitoring system in a few river launches in Loreto look promising, however (Tenkanen et al. 2014).

***To conclude:** This thesis gives examples of how different types of data sources and their combinations can be used in accessibility analyses. The combination of computational accessibility models with data on residents' realised mobility patterns is particularly interesting because it reveals discrepancies between the “optimal” and true patterns of mobility. Future data needs identified in this section share a common feature: they are all in one way or another related to the temporal dynamics of accessibility. Indeed, combining the aspects of space and time into a spatio-temporal approach is considered to be a promising direction for future transport and accessibility research (Lam et al. 2014). Mobility data mining and GPS-based monitoring systems in particular provide novel and intriguing possibilities for future mobility and accessibility analyses both in Greater Helsinki and in Amazonia.*

5.1.5 There is a need for openly available accessibility tools

The computational accessibility tools used in the case studies of Greater Helsinki (MetropAccess-Digiroad, MetropAccess-Reititin) (III, IV, V) are examples of accessibility instruments that could be regarded as (spatial) planning support systems (PSS). In general, such systems have been developed in order to enhance the role of information and knowledge in planning (Carsjens & Ligtenberg 2007; Vonk et al. 2007; Bierman 2011), and lately, the need to incorporate accessibility tools for these systems is identified (Te Bömmestroet et al. 2014). It is, however, a challenging task to deliver the results of academic research into practical level planning (e.g., McKinley et al. 2012) and to turn the developed methodologies into operational planning support instruments. In particular, the “black box effect” of scientifically rigorous tools tends to reduce the usability of such systems in practice (Geertman & Stillwell 2004; Vonk et al. 2005; Te Brömmelstroet et al. 2014).

Recent development towards open science (Willinsky 2005; García-Peñalvo et al. 2010; Wolkovich et al. 2012), including not only open access publishing but also sharing data openly, using open source code for computational tools and licencing them as openly as possible, can potentially help us to bridge the gap between academic and planning realities (c.f. Fitzgerald et al. 2013; Jetzek et al. 2014). Following these ideas, the tools that were used in this thesis are based on open source code and made freely available for anyone to use, with a particular intention to be used by urban planners. The currently on-going City Plan process has already benefited from these tools (see City Planning Department of Helsinki 2012). Furthermore, our research project has published a freely available accessibility dataset for the Greater Helsinki area; the MetropAccess travel time matrix⁵ consists of multimodal travel times and distances between different locations in the Greater Helsinki area (Toivonen et al. *forthcoming*). The availability of such general and readily computed accessibility data can potentially even further facilitate the use of accessibility information in planning and decision-making processes.

***To conclude:** While the methodological development in academic literature has value per se, its policy-relevancy and usability are not really tested until the methods reach the planning practice. The computational tools used in this thesis provide examples of accessibility instruments that can be seen as parts of a planning support system. Distributing the developed tools as openly as possible is particularly valuable since open licensing tends to facilitate their (re-)use and foster open knowledge accumulation.*

5.2 Contextual findings

5.2.1 The same space can have parallel accessibility realities for different individuals

As examples from this thesis demonstrate, the spatial patterns of accessibility are to a large degree determined by the spatial organisation and characteristics of the transport networks (I, III). In Loreto, distances and travel times to the main regional centre are generally very long and many areas in the Peruvian Amazonia can be considered poorly accessible; travelling

⁵ The dataset is freely available at <http://blogs.helsinki.fi/accessibility/data/metropaccess-travel-time-matrix/>

from the different parts of the study region to the central city typically takes several days, and the transport options vary highly across the region (I). Generally speaking, communities located along the main channels (Amazon, Ucayali and Marañón) have clearly better levels of accessibility towards Iquitos in comparison to communities located along smaller meandering rivers – even though these might appear equally well positioned if looking at as-the-crow-flies distances only. Travel speeds along the major channels are faster and the frequency and capacity of river traffic is much higher. Owing to the spatial structure and the connectivity of the rivers, particularly poorly accessible areas are located along the border rivers Yavari and Putumayo.

The above described patterns describe the accessibility landscape of rural people that have the possibility to travel by river launches. Different individuals may, however, experience the same space very differently, depending on their personal characteristics and on the assets and opportunities available for them (Kwan & Weber 2003; Geurs & van Wee 2004). The access (or lack of it) to different travel modes might completely change the accessibility picture; in the case of Loreto, an individual travelling by canoe or speed boat would probably experience the distances in a very different way.

The results from Greater Helsinki touch upon the individual component of accessibility (see Geurs & van Wee 2004) by describing the accessibility patterns by different travel modes. The PT users' route options are much more restricted than those of car users, and in the whole study area, travel times by public transport are generally notably longer than travel times by car (III, IV). These differences present considerable variation across the area; the modal travel time disparity appears smallest in the city centre area and along the railway lines. The largest differences in favour of car are found along the edges of the study area and in the vicinity of the outer ring road (III). Such a pattern, highlighting the city centre as an area of more equal transport opportunities by car and PT is typical in many cities where the PT network is oriented towards the city centre (e.g., Kawabata 2009; Elldér et al. 2012).

***To conclude:** This thesis provides quantitative descriptions and visualisations of the spatial patterns of accessibility in the case study areas. In Peruvian Amazonia many areas are poorly accessible from the main regional centre and people living along the major rivers have a relative advantage in form of shorter travel times and more frequent traffic between their home communities and the city of Iquitos. In Greater Helsinki the accessibility patterns appear different for the users of different travel modes; travel times by public transport are notably longer than travel times by car, with the city centre and areas along the railway lines being the only exceptions to this pattern.*

5.2.2 Accessibility to urban centres influences rural livelihood options and human pressure on forest resources

The ways in which accessibility shapes land use (cf. von Thünen 1827 / Hall 1966; Hansen 1959) become particularly visible in the Amazonian case studies. The patterns of accessibility have clear impacts on the livelihoods of the rural dwellers (I) and on the human-induced land-use pressure (II). Considering the most prominent livelihoods in the region, commercial

farming and extraction of non-timber forest products, accessibility is a key determinant of opportunities. Travel times to the main markets determines what kind of products are feasible to be sent to markets (I): easily perishable produce (herbs, fresh fish, etc.) have rather limited potential production zones whereas produce with longer shelf life (plantain, dried maize, etc.) can be transported from more remote places. Furthermore, the frequency and capacity of transport are indicative of the possible level of market integration (I). Producers living in communities along regularly served river boat routes are able to keep better track of the market situation in the city, and the marketplace forms a part of their daily lives. On the contrary, poor transport opportunities in communities that receive limited boat traffic can be an important barrier for trade; all earnings from the harvest can be lost due to missing transport options (cf. Hilling 1996; Wickramasinghe 1997; Porter 2002).

High levels of accessibility in biologically valuable tropical regions are typically connected with increased land-use intensity and pressure on existing resources (Imbernon 1999; Laurance et al. 2002; Alvarez & Naughton-Treves 2003; Peres & Lake 2003; Fenley et al. 2007; Oliveira et al. 2007; Müller & Mburu 2009; Salo & Toivonen 2009; Salo et al. 2011; Walker 2012). Results of paper II confirm that quantitative accessibility models indeed help us to understand and predict patterns of deforestation. Even the most simple (Euclidean) accessibility inputs improved the performance of the LUCC model in comparison to a model that had no accessibility information at all, and even better predictions were achieved when accessibility was quantified in a more sophisticated way.

***To conclude:** Accessibility to regional centres is crucial for human livelihoods and it also regulates human pressure on the environment. Quantitative data on accessibility can serve as an input when analysing the spatial patterns of human livelihoods (exemplified by the modelling of potential production zones for different agricultural produce) and land-use pressure (exemplified by the deforestation modelling).*

5.2.3 Accessibility by different travel modes guides the environmental sustainability of urban residents' daily mobility

In paper IV we estimated the amount of CO₂ emissions resulting from travelling to libraries and assessed the role of different service allocation strategies employed by the different municipalities in the study area. Our results show that 52.2% of library customers used a “climate-optimal” library (which they access with lowest emissions) and the remaining 47.8% chose a non-optimal destination library. Differences between the municipalities were notable. In Espoo, where the local libraries have been consolidated into bigger entities, and thus, the service network is relatively sparse, the modelled CO₂ load of an average library trip was nearly twice as big as the corresponding value in Helsinki, where the library network is relatively dense. Furthermore, in Helsinki, the share of emissions resulting from non-optimal trips was much lower than in other municipalities. This indicates that choosing the second or third closest alternative destination does not make that big of a difference for emission rates in a dense service network. In all, our results show how different municipal service allocation strategies can lead to varying emission patterns resulting from daily travel. Our findings support the hypothesis that mix-use neighbourhoods can reduce average travel distances and

increase the use of sustainable travel modes (see Newman & Kenworthy 1989; Vance & Hedel 2007; Holz-Rau et al. 2014); the maintenance of dense service networks appears to be a climate-wise sustainable strategy because it seems to be connected to overall shorter travel distances and to the use of less carbon-intensive travel modes (IV).

The environmental sustainability of residents' daily mobility was also assessed in paper V, which focused on residents' mode choices and their optimality in terms of travel time. In general, the residents in Kuninkaankolmio had rather sustainable daily mobility practices. Their daily trips were typically short (median 1.8 km), and non-motorised travel modes were the most popular. Although the modal share of PT was clearly the lowest, it was frequently used on longer trips (particularly towards the city centre). The fastest travel mode was chosen approximately as often as a comparatively slower mode. When residents made a non-optimal mode choice (i.e., did not select the fastest travel mode for a particular journey), the mismatch was in the great majority of cases favouring less carbon-intensive travel modes (that is, PT or NMT was chosen instead of car, and NMT instead of PT). The most notable exception from the otherwise rather sustainable travel behaviour was related to shopping trips (cf. Buys and Miller 2011; Næss 2012); these trips tended to have the most carbon-intensive mode choices and residents' typically chose the car even if it was not the fastest choice for the particular journey.

***To conclude:** Accessibility to services and other daily activities is an important factor influencing residents' travel decisions. Our case study of library customers in Greater Helsinki show that a dense service network structure is connected to shorter travel distances and the use of less carbon-intensive travel modes. Furthermore, with the exception of shopping trips, people in our study area show rather sustainable travel behaviour by travelling relatively short distances and by often choosing less carbon-intensive travel modes for their daily trips, although faster (and more carbon-intensive) modes would also be available.*

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