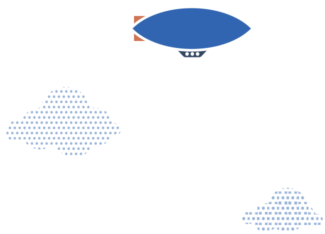
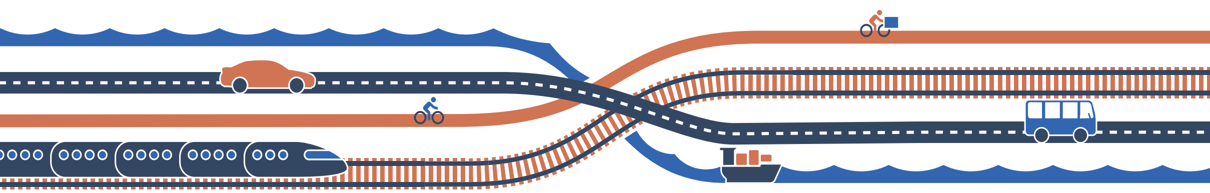


Travelling Beyond Spatial Analysis

The Impact of Temporal and Personal Restrictions on Equitable Access to Opportunities



by Koos Fransen

GHENT UNIVERSITY

De impact van tijd- en persoonsgebonden restricties
op een gelijkwaardige toegang tot voorzieningen

Travelling beyond Spatial Analysis: The Impact of Temporal and Personal Restrictions on Equitable Access to Opportunities

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Proefschrift ingediend tot het behalen van de graad van
Doctor in de industriële wetenschappen

Vakgroep Geografie
Voorzitter: prof. dr. P. De Maeyer
Faculteit Wetenschappen

Vakgroep Civiele Techniek
Voorzitter: prof. dr. ir. P. Troch
Faculteit Ingenieurswetenschappen en Architectuur

UNIVERSITEIT
GENT

Academiejaar 2017 - 2018

ISBN 978-94-6355-074-1
NUR 905, 901
Wettelijk depot: D/2017/10.500/109

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Dean: "Sal, we gotta go and never stop going 'till we get there."
Sal: "Where we going, man?"
Dean: "I don't know but we gotta go."

Jack Kerouac in On the Road, 1957

Word of gratitude

Conducting a PhD is actually very similar to scuba diving; roughly plan your route, jump right in, enjoy yourself and, most importantly, keep breathing, and you'll be just fine.

Koos Fransen, 2017

For those who got to know me these past four years as a colleague or as a friend (mostly as both), the analogy between writing a doctoral dissertation and travelling – or being on the road – will not come as a surprise. It took me quite the effort to process one of my favorite pastimes in my dissertation title, and I will continue on this stretch for thanking the multitude of magnificent people who have helped me being where I am today, writing my thoughts on paper at this very moment.

As all good travel stories, I should start with the beginning. And for actually starting – and, of course, eventually finishing – my PhD, I have to extensively thank my two supervisors or, considering my analogy, my guides throughout my PhD journey. Philippe, you provided me with the opportunity to continue on my master thesis topic, which mainly focused on the concept of accessibility; a topic that has interested me from the very beginning. Your support in applying for a scholarship after my studies was very welcome, and from that moment on I have always considered you the researchers' tourist office: the helpful person with the right contacts everywhere, the necessary information at hand (when asked for) and a ton load of maps lying around in his office. Moreover, I greatly appreciate the freedom you gave me during these four years in finding my own trodden path. In contrast to your laid-back, let-him-be-he's-doing-just-fine way of guidance, my next victim for praise can be considered as the typical look-around-and-enjoy type of guide. Geert (sometimes also referred to a 'Greet' or 'Greedt'), as a respective promotor should, you showed me every tip and trick in the book to work more efficiently, explore more grounds and develop myself to the fullest. Yet you also motivated me that there is always more to do – in my PhD as well as in life in general – and reminded me to never stop enjoying every part of it. I had the pleasure of joining you in exploring exotic temples in India, making fishing holes in frozen Finnish lakes and even ploughing through – both literally and figuratively – muddy waters in Bertrix. But more importantly, you made me feel at home in the great world of academia, even when at times the road seemed long and hard to travel. And in all this, no time constraints were large enough to hold you back from taking a break to go over a paper, brainstorm on an idea or just make small talk (or indeed, gossip). Thank you for everything.

On my great PhD expedition, there are two additional people that deserve as much praise in guiding me throughout the journey. Tijs and Steve, I will call you guys the locals, the ones that led me to a destination's good spots while avoiding the boring tourist traps. In the bewildering world of transportation, you definitely made sure I found my way. In addition, you introduced me to some of my major 'academic idols' (e.g., the part-time philosopher and always captivating Karel Martens or the powerful yet charming Karen Lucas), with whom I had the pleasure of discussing my research topic or working together with thanks to you. Tijs, you gave me the kick start that I so eagerly needed, with an accepted IWT grant proposal and two accepted journal articles within my first year of research. I enjoyed working with you, and I can now honestly say that the first year was the most productive one, because I had the pleasure of travelling into academia alongside you. I wish you all the best with your family and your career, and maybe someday a return ticket to academic research. Steve, just as Tijs boosted my moral in the preliminary stage of my PhD, you flew me in to Toronto, made me part Canuck and got me on the academic path again during the second half of my PhD. I really enjoyed my time in Toronto, and I will never forget your efforts in helping me on the Utah paper while you and Jess were expecting little Raphael (and you bringing him to our farewell dinner when he was only a couple weeks old). I wish you guys the best of luck in your new home, say 'hi' to Theo and Jess, and I will always be looking forward to our next Belgian (or yeah, why not Canadian) beer together.

As many of you know, travelling abroad – be it for conferences, workshops or just downright holidays – has encompassed a large portion of my time as a PhD student. Nonetheless, I have fallen deeply in love with my hometown and the capital of my time as a (PhD) student: the bustling city of Ghent, where – without explicitly quoting Will Smith – I spent most of my days. Herein, I have many travel companions to thank. As an industrial engineer with a promotor in geography and a research interest in mobility and spatial planning, I had the pleasure of getting to know three groups of colleagues. Our memorable times together could suffice as a reason for me to flunk my PhD and stay just a little longer. First, I would like to thank all the colleagues in the Geography department at the S8. I had the pleasure of sharing an office with Tijs and Bart, and later with Samuel, Pepijn and Nina. I have no doubt that we will soon play some funky, jazzy tunes at a jam session in the Kinky Star, drink an Aperol Spritz on a lazy Friday afternoon or row down the Watersportbaan together. I should definitely also thank the Barts, Marijke, the Anneliezen, Jasper, Tim, Britt, Berdien, Laure, Kristien, Lieselot, Kevin, Jochem, Jeffrey, Jeroen, Lander, the Michiels, Lien, the Hannes, Freke, Jonas, Leen, Ann, Niels and Soetkin for the (bachelor) parties, escape games, apero's, conferences, programming help, ping pong championships, collaboration, assistentenweekendjes, etc. Thank you all for making my (what now really feels like limited) time at the S8 that much fun. In addition, a special word of gratitude goes out to Helga. Thank you for all your help and kind words of support, without you my PhD would definitely have been an administrative wreck. I wish you the best with your painting and calligraphy, and hopefully we can see each other soon over a good bowl of pasta topped with Ruben's delicious olive oil (not phrasing). Second, I would like to thank all the colleagues at the Schoonmeersen. Here, I had the pleasure of sharing an office with Hanne, Kizzy, Gieljan, Marijke, Charlotte, Sara and Sven, and although there was some office rivalry, Arne, Anthony and Leo "working" in the other office deserve as much praise. I am sure that I will hop in for a 'frigomomentje' now and then, join you on the dance floor at the Oude Vismijn, get my butt kicked in padel or archery or just casually meet up with you guys in Ghent. And for those of you still travelling down the PhD road, I wish you the best of luck. In particular, I would also like to thank Hanne for our pleasant times together. It is always nice when colleagues become your friends, but it is an even greater pleasure when one of your friends joins you as your colleague. Good luck with the GIS course, I am sure you will do fine without me. My gratitude also goes out to the slightly-less-younger generation of colleagues: Frank, Dirk, Tom, Veerle, Wouter, Hilde, Kathleen, Ignaas and Marc. I am sure we will catch up in the coffee corner. Last but not least, I would like to thank my colleagues at the AMRP. Karel and Suzanne, good luck on your impending PhD dissertation deadline. Thomas and Els, the best of luck on your new professional adventures. Barbara and Beitske, I am convinced that you will keep the AMRP wheel turning, through the prospect of a great number of new projects. And, of course, Luuk, Maja and Jurgen (and the rest of the researcher/teacher staff), thank you for welcoming us surveyors into the AMRP group. I hope to see you guys again at the next Gents' Delight concert or just casually meet up for drinks to elaborately discuss the complex Flemish spatial planning context (and, of course, its impact on the Flemish mobility landscape, and vice versa).

On my journey, I also had the pleasure of collaborating with a large number of people working in a wide range of domains seeking similar answers to similar research questions. Those people supported me by sharing their knowledge on topics I was not really acquainted to, providing data I did not easily have access to or exchanging ideas I had not remotely thought about. In this respect I would like to thank Stijn Van Keer and Christele Van Nieuwenhuyzen (Kind & Gezin), Bart Seghers, Cécile Dusart and Koen De Broeck (De Lijn), Pieter Colpaert (iRail), Els Vandenbroeck, Evelien Bossuyt and Sarah Martens (Mobiel 21 vzw), Lies De Landtsheer, Willem Vansina and Steven Marx (VDAB) and Diedrik Gaus, Peter Bogaert, Sabine Denolf, Geertrui Vanbelleghem, Els Verhasselt, Eric Dirikx and Els Bauwens (Stad Gent). I sincerely hope that my research has inspired and enticed you in the same manner as your efforts have contributed to my dissertation and, far more important, my personal way of thinking about spatial planning, transportation and accessibility. In addition, I would like to thank all of the coauthors who aided me in projecting my stories into academically acclaimed research papers or book chapters as well as all reviewers who critically assessed my work in order to constantly increase its quality. And Dries, thank you for helping out with the cover layout, you have done a magnificent job.

To conclude, I have a long list of friends and family to thank for supporting me over the past four years. As the praise you all deserve goes beyond what can be written down in words, I will briefly project various fragments of adventures I sincerely wish to partake with you. Mom and dad, may we have numerous Fransen family lunches at the Kleemburg terrace overlooking the 'Den Draad stadspark' in Gentbrugge. Teun, may we have an elaborate barbecue in the garden of your new home while discussing one of our many joint hobbies. Job, may we meet each other in Australia, take a break from life and travel the country you have grown so fond of. Simon, may we explore the most beautiful places in Central America, as a prelude of the many adventures we will take together. Niels, Sylvia, Basil and Anaïs, may we develop our own boardgame (maybe something mosquito-themed?) and present it at the International Spieltage in Essen. Arne, may we walk the Cape Wrath trail, as a follow up to our magnificent journey at the Arctic Circle Trail in Greenland. Jasper, may we finally succeed in meeting up in Germany and play a game of FIFA 13 before watching an alternative movie and camping in the countryside. Jonas, Pieter-Jan, Jeroen, Pieter, Thomas, Lode, Domien, Laurens and Andries, may Gent Ready finally have a personalized team photo with Get Ready (of course, while I am

carrying the Gouden Stier). Antoon, Simon and Sander, may Gents' Delight tour through Europe with our own band van. Jeroen, may we climb our first outdoor wall together (yes, in Portugal is okay for me). Ruben, may we meet up for some (half-drunken) philosophical discussions over a Negroni. Emma, may we partake in the Athens marathon and beat your niece to the finish. Antoon, may we finally learn to stop 'ice hockey'-style while ice skating. Lien and Willem, may we take Pastis for a nice long walk until his tiny legs refuse to carry him any longer. Comrades from Thor, may we celebrate our promotion to second division in De Croone. Friends from the dive club De Manta, may we spot a snotolf, sea horse or paarse waaierslak while diving the Oosterschelde. Nate and Jeff, may we take a trip to Lake Simcoe next time I am visiting Toronto. Raphael, may we meet up in Brasilia and write that paper we have been taking about for ages. Musicians from the Evergems Groot Lichtbal, may we nail a perfect Mouchti Mazurka and make everybody dance without a worry in the world.

And finally, I would also like to thank Inez. Our journeys took a different turn on the fork in the road that is life, but the PhD student in me will always remain grateful for having my most beautiful adventures during these four years with you.

Summary

The rise of the automobile in the post-World War era has brought the concepts of transportation and mobility for personal use to the foreground. What started as a luxury good for the more well-off, swiftly evolved to a common good for the masses due to the combination of an ever-growing demand and vast improvements in the industrial production chain. The increased use of private motorized vehicles has strongly altered the built environment in Flanders as well as its inhabitants' travel behavior, and, as such, the general living standards. However, this has also led to an increasing societal strain of the various externalities related to travel by car, enhanced by the diminishing popularity of public transportation systems as an adequate alternative for daily travel. An important, often understudied aspect is transport's ability to construct an unequitable distribution of the benefits generated by the (combination of) transport systems. Herein, concepts of transport poverty and social exclusion in the domains of transportation and spatial planning are often neglected in academic research, as the majority of accessibility-focused studies start from an overly simplified situation that only accounts for spatial constraints. In order to grasp the complexity of the matter at hand, research needs to additionally address the temporal and personal constraints that impact a person's accessibility. The proposed dissertation provides a structural framework that supports the claim for more detailed, person-based accessibility measures, and illustrates five case studies within this theoretic framework.

The first chapter serves as a general background and introduces the reader to the concepts of mobility and accessibility. The author aims to highlight how the concept of accessibility is better suited to address demand-driven transportation models, as it goes beyond merely providing mobility to the transport system users. The past two decades, there has been a growing focus on the social implications of transport planning in addition to the well-studied economic and environmental outcomes. In both scientific research and policy support, aspects of mobility and accessibility – or even transportation in general – are, however, often considered from a purely spatial point of view. This leads to an incorrect representation of the actual situation, as temporal as well as personal restrictions strongly impact an individual's level of accessibility. Resultantly, transport policies are considered to possibly generate inequitable accessibility effects that favor certain population groups

above others. Various conditions of transport disadvantage remain under the radar, which hinders an equitable distribution of transport benefits and exacerbates situations of social exclusion. Herein, the aspect of fairness of the transport system and its users is highly complex and strongly dependent on the way justice is defined. The applied case studies indicate that each research question is dependent on different input datasets and required outcomes. Therefore, this dissertation proposes a framework that highlights the importance of incorporating spatial, temporal and individual constraints into accessibility analysis to better understand issues of transport disadvantage. The hypothesis is that person-based space-time accessibility measures are more suitable for equity appraisal than place-based measures and allow researchers or policy makers to address policy issues that cannot be addressed by using purely spatial accessibility measures. Although primarily applied for spatial analysis, given the right datasets, geographic information systems (GIS) can support accessibility measures for all three dimensions: in addition to space, also time and the individual.

The second chapter provides a preliminary case study example of the extent to which accessibility measures that introduce mobility patterns into the analysis differ from commonly applied, purely spatial accessibility measures. An adaptation of the well-known two-step floating catchment area measure assessed accessibility to childcare services based on the commute from the home to the work location instead of the static night-time representations of the population. The results showed significant differences in accessibility levels and pinpoint the importance of giving heed to temporal variations in supply and demand as well as more complex travel behavior in general. The third chapter complements this idea, and focused on the temporal variability of the public transport system and this system's ability to bring individual's to a desired location. Herein, public transport gaps were identified as areas where the transit provision does not match the need. The chapter illustrated that high public transport gaps mainly affect suburban areas and that these gaps are dependent on the time people are willing or mandated to travel. In addition, it showed that although transit provision varies over space, the actual need for transportation is strongly influenced by individuals' characteristics. Whereas this chapter examined the accessibility to a wide range of opportunities using one transport system, it did not consider multimodal differences in access to one specific opportunity. In the fourth chapter, this limitation was addressed by examining the impact of the education level and driver's license – and, therefore, the transport mode – on access to job opportunities. As such, the chapter aimed to focus on the planning policy gap on the relationship between disadvantaged population groups and their spatio-temporal, multimodal access to employment. The chapter's results highlighted the importance of both a higher educational level and driver's license ownership to maximize one's accessible job opportunities. This exposed important aspects of inequity in job seekers' access to job opportunities, especially for the most vulnerable groups, which has important ramifications for both spatial planning and transport policies in Flanders. In addition to the vast amount of literature on accessibility, the first three case studies started from the general assumption that higher levels of potential accessibility lead to higher levels of perceived participation and satisfaction. However, to date, no clear pattern of correlation between an individual's accessibility and his or her participation in activities has been found due to the aggregated and often place-based nature of the applied methodologies. The fifth chapter examined this relationship by comparing an aggregated, place-based accessibility measure to an individual, person-based accessibility measure. The study underlined the need for more person-based accessibility analysis, as it proved better suited to address the accessibility-participation relationship, as would logically be expected. The place-based method, on the contrary, showed an improbable, negative relation with activity participation, indicating the possible counterintuitive conclusions that might be drawn from using these measures. Although the chapter illustrated the relationship with accessibility, it is unclear to what extent lower accessibility leads to aspects of social exclusion on the individual level. In the sixth chapter, the relationship between transport disadvantage and employability was examined by assessing job seekers' accessibility to job openings that correspond to their individual preferences and competences. The resulting model allowed to capture the person-specific labor-market opportunities for an individual and construct a predictive model for long-term unemployment, in addition to the predictive capacity of various socio-demographics. The chapter pinpointed that in Flanders, various inequities in long-term unemployment exist, with some groups having two or three times higher probabilities of being long-term unemployed.

The seventh chapter summarized the degree to which the various case studies have succeeded in answering the problem statement and research question. As hypothesized, person-based, space-time accessibility measures provide numerous advantages over the commonly applied place-based measures. Nonetheless, they also pose new limitations, especially in terms of data requirements, calculation complexity and policy implementation. Herein, a constraints-led approach is constructed and three important focal points are defined: 1) delineating the constraints and defining concepts of social and transport disadvantages, transport equity and social exclusion, 2) perception and communication of possible transport-related equity issues through (academic) research, and 3) establishing policy-based interventions for transport equity appraisal. These three focal points are translated into a number of policy recommendations. First of all, a clearer and more comprehensive definition of equity in transportation is needed. This will allow policy makers to set clear goals and provide researchers with a foundation to objectively assess if these goals were, are or will be met in transport investments. This definition should travel beyond the spatial dimension and incorporate temporal and personal restrictions. Herein, a better coordination between academia and policy is a necessity, as academic research has the ability to provide a solid foundation for policy support. Moreover, transportation is too frequently addressed as an isolated policy domain. The way people travel has a strong impact on their built environment and the quality of life, and, as such, is strongly related to, for example, spatial planning, housing or economics, or a wide range of other policy domains. Research in the field of transportation – be it within academia or policy – should aim to better accommodate the link with other research domains, especially with spatial planning. Going beyond a merely spatial point of view by addressing temporal and individual aspects can support a more effective fine-tuning to other policy domains. Finally, transport policy should focus more strongly on fostering participation and dialogue in order to attain a more equitable distribution of transport benefits. The conceptual framework supported by the case studies as proposed in this dissertation provides a theoretical background in person-based accessibility measures' ability to better highlight and address transport equity issues. Nonetheless, these assumptions should be underlined by translating this theoretical background to real-life applications in the field. This is only possible through thorough participation with the various stakeholders that shape accessibility in space and time. Future accessibility research should bear in mind the proposed work areas in order to better answer the projected policy recommendations.

Samenvatting

De opkomst van de auto in de naoorlogse periode heeft er in de laatste helft van de 20e eeuw voor gezorgd dat de concepten personenvervoer en mobiliteit binnen een hele reeks aan beleidsdomeinen op de voorgrond traden. Hoewel aanvankelijk beschouwd als een luxe goed voor welgestelde burgers, groeide de auto al snel uit tot een vaste waarde voor het grote publiek dankzij de steeds groeiende vraag en aanzienlijke verbeteringen in het industriële productieproces. Het substantiële gebruik van gemotoriseerd, privaat vervoer heeft het Vlaamse landschap zowel als het reisgedrag van diens inwoners – en bijgevolg de levensstandaard in het algemeen – drastisch veranderd. Dit leidde tot een toenemende druk op de maatschappij door de negatieve effecten van autoverkeer, verder versterkt door de dalende populariteit van het openbaar vervoerssysteem als adequaat alternatief voor de dagelijkse vervoersvraag. Een belangrijk, vaak onderbelicht aspect is de onbillijke verdeling van de voordelen die vervoerssystemen kunnen genereren. Het merendeel van bereikbaarheidsstudies vertrekt van een sterk vereenvoudigde situatie waarbij enkel rekening gehouden wordt met puur ruimtelijke restricties. Bovendien worden de concepten vervoersarmoede en sociale uitsluiting in de domeinen van transport en ruimtelijke planning in academisch onderzoek vaak over het hoofd gezien. Om de complexiteit van de onderzochte materie beter te doorgronden is bijkomend onderzoek nodig dat de tijd- en persoonsgebonden beperkingen in rekening brengt. Het voorgestelde doctoraatsproefschrift stelt een structureel onderzoekskader voor ter ondersteuning van de evolutie naar persoonsgebaseerde bereikbaarheidsanalyses en onderzoekt vijf casestudies binnen dit theoretische kader.

Het eerste hoofdstuk beschrijft de algemene onderzoeksachtergrond en introduceert de concepten mobiliteit en bereikbaarheid. Daarbij wordt aangetoond dat bereikbaarheid beter geschikt is voor vraaggestuurde transportmodellen, aangezien dit concept verder reikt dan enkel het aanbieden van mobiliteit aan de gebruiker van het vervoerssysteem. Naast de frequent onderzochte impact op de economie en de leefomgeving, is de laatste twee decennia de interesse in de sociale implicaties gerelateerd aan transportplanning toegenomen. Zowel in wetenschappelijk onderzoek als in het beleid worden mobiliteit en bereikbaarheid – en zelfs transport in het algemeen – echter vanuit een puur ruimtelijk standpunt belicht. Dit leidt tot een incorrecte weergave van de werkelijke situatie,

aangezien tijdsgebonden en persoonlijke restricties beiden een sterke impact hebben op de bereikbaarheid van een individu. Bijgevolg kan het transportbeleid mogelijks onrechtvaardige effecten genereren die bepaalde bevolkingsgroepen meer ten gunste komen. Daardoor worden bepaalde vormen van vervoersarmoede niet aan de oppervlakte gebracht, hetgeen een gelijkwaardige verdeling van bereikbaarheid in de weg staat en zo situaties van sociale uitsluiting in de hand werkt. De uitgewerkte casestudies tonen aan dat elke onderzoeksvraag afhankelijk is van de beschikbare input informatie en verwachte uitkomsten. Dit proefschrift stelt een theoretisch kader voor dat focust op het incorporeren van zowel ruimtelijke, tijdsgebonden als persoonlijke restricties in bereikbaarheidsanalyse om zo problemen gerelateerd aan vervoersarmoede beter te doorgronden. Hoewel geografische informatiesystemen (GIS) voornamelijk gekend zijn en gebruikt worden om ruimtelijke vraagstukken op te lossen, hebben ze ook veel potentieel om ingezet te worden in vraagstukken die de drie dimensies omvatten: de ruimte, de tijd en het individu.

Het tweede hoofdstuk omvat een eerste casestudie die peilt naar het verschil tussen bereikbaarheidsanalyses die verplaatsingspatronen incorporeren en de puur ruimtelijke modellen. Daarvoor werd een op de vaak gebruikte 'two-step floating catchment area' gebaseerde methode ontwikkeld om de bereikbaarheid naar kinderopvang te meten, rekening houdend met de woon-werkverplaatsing in plaats van de statische thuislocatie van de bevolking. De resultaten tonen significante verschillen in bereikbaarheid bij gebruik van beide methodes en onderstrepen het belang van zowel tijdsgebonden variatie in vraag en aanbod als complexer reisgedrag in het algemeen. Het derde hoofdstuk sluit hierbij aan, maar richt zich op de tijdsgebonden variatie van het vervoerssysteem zelf en de mate waarin het vervoerssysteem erin slaagt een individu naar een gewenste locatie te brengen. Daarbij worden mismatches in openbaar vervoer aangeduid als gebieden waar het aanbod aan openbaar vervoer niet aan de nood tegemoetkomt. Het hoofdstuk illustreerde dat de meest nadrukkelijke mismatches voornamelijk voorkomen in suburbane regio's en dat deze mismatches afhankelijk zijn van het tijdstip waarop mensen zich willen of moeten verplaatsen. Bijkomend wordt aangetoond dat hoewel het aanbod variabel is over de tijd, de eigenlijke vraag beïnvloed wordt door de specifieke karakteristieken van een individu. Dit hoofdstuk onderzoekt de bereikbaarheid naar verschillende opportuniteiten door gebruik te maken van één vervoersmodus: het openbaar vervoer. Desondanks hield het onderzoek geen rekening met multimodale verschillen in de toegang tot één of meerdere activiteiten. Het vierde hoofdstuk speelt hierop in door de impact van zowel opleidingsniveau als het bezit van een rijbewijs – en bijgevolg de keuze van vervoerswijze – op de toegang tot vacatures te onderzoeken. Hierdoor tracht dit hoofdstuk een antwoord te bieden op het gebrek aan planningsbeleid dat handelt over de relatie tussen benadeelde groepen en hun tijd-ruimtelijke, multimodale toegang tot werkgelegenheid. De resultaten benadrukten het belang van een hoger opleidingsniveau en het bezitten van een rijbewijs om de kansen van een werkzoekende op de arbeidsmarkt te maximaliseren. Dit brengt ongelijkheden in de toegang naar werkgelegenheid aan het licht, en voornamelijk voor de meest kwetsbare groepen, wat dan weer aanzienlijke gevolgen heeft voor ruimtelijke planning en transportbeleid in Vlaanderen. Net als een groot aandeel van het onderzoek naar bereikbaarheid in het algemeen, vertrokken de eerste drie casestudies van de veronderstelling dat betere potentiële bereikbaarheid leidt tot meer participatie in activiteiten, en bijgevolg een hogere graad van voldoening. Desondanks werd tot op heden geen duidelijke correlatie gevonden tussen de bereikbaarheid van een individu en diens participatie in activiteiten wanneer gebruik gemaakt werd van een geaggregeerde en vaak op locatie gebaseerde bereikbaarheidsanalyse. Het vijfde hoofdstuk onderzoekt deze relatie door een geaggregeerde, op locatie gebaseerde methode voor bereikbaarheidsanalyse te vergelijken met een individuele, op de persoon gebaseerde methode. Het onderzoek benadrukt de nood aan een bereikbaarheidsanalyse die het individu centraal stelt, aangezien aangetoond wordt dat dergelijke methodes – zoals logisch kan verwacht worden – beter geschikt zijn om de bereikbaarheid-participatie relatie te benaderen. Methodes die de locatie centraal stellen, resulteren echter in een niet te verwachten, negatieve relatie met participatie, wat aangeeft dat het gebruik van deze methoden kan leiden tot mogelijke contra-intuïtieve conclusies. Hoewel dit hoofdstuk de bereikbaarheid-participatie relatie aantoont, blijft het onduidelijk in welke mate lagere bereikbaarheid bepaalde aspecten van sociale uitsluiting op niveau van het individu als gevolg heeft. In het zesde hoofdstuk wordt de relatie tussen vervoersarmoede en tewerkstelling onderzocht door de bereikbaarheid van werkzoekenden tot vacatures die corresponderen met hun individuele voorkeuren en competenties te bepalen. Het resulterende model laat toe voor een individu de persoonlijke opportuniteiten op de arbeidsmarkt te capteren en – bijkomende aan het voorspellend vermogen van de verschillende socio-demografische gegevens – een voorspellend model voor langdurige werkloosheid op te stellen. Het onderzoek toont aan dat Vlaanderen verschillende ongelijkheden in langdurige werkloosheid kent, waarbij sommige groepen twee tot drie keer meer kans hebben langdurig werkloos te blijven.

Het zevende hoofdstuk concludeert in welke mate de verschillende casestudies een antwoord op de probleemstelling en onderzoeksvragen kunnen bieden. De hypothese dat individuele, tijdruimtelijke bereikbaarheidsanalyse verschillende voordelen biedt ten opzichte van de momenteel vaak toegepaste ruimtelijke, op locatie gebaseerde methodes werd aanvaard. Desondanks brengen ze ook nieuwe beperkingen aan de oppervlakte, voornamelijk met betrekking tot de nodige data en de complexiteit van de berekeningen. Daarbij werd een restrictie-gebaseerde aanpak vooropgesteld en werden drie belangrijke werkpunten aangeduid: 1) de afbakening van de restricties en het definiëren van sociale en transportgerelateerde onrechtvaardigheid en sociale uitsluiting, 2) perceptie en communicatie van mogelijke transportgerelateerde onrechtvaardigheid met behulp van (academisch) onderzoek, en 3) de uitwerking van beleidsmaatregelen met het oog op het beoordelen en nastreven van billijkheid in transport. Deze drie werkpunten worden vertaald naar verschillende beleidsaanbevelingen. Ten eerste is er nood aan een duidelijkere en meer allesomvattende definitie van billijkheid in transport. Hierdoor kunnen beleidsmakers duidelijke doelen stellen en kunnen onderzoekers vertrekken van een vastgelegde basis waarop eerdere, huidige of toekomstige investeringen in transport op een objectieve wijze kunnen beoordeeld worden. Deze definitie moet verder reiken dan enkel de ruimtelijke dimensie door zich simultaan ook op de tijdgebonden en persoonlijke restricties te richten. Daarbij is een betere afstemming tussen de onderzoekswereld en beleid noodzakelijk, aangezien wetenschappelijk onderzoek een belangrijke rol kan spelen in het uitstippelen van de beleidslijnen. Bovendien wordt transport te vaak behandeld als een op zichzelf staand beleidsdomein. De manier waarop mensen zich verplaatsen heeft een sterke impact op de bebouwde omgeving en de levenskwaliteit, en is bijgevolg sterk gerelateerd aan bijvoorbeeld de ruimtelijke planning, het huisvestingsbeleid of de economie, of aan een breed gamma van andere beleidsdomeinen. Onderzoek in transport – academisch of beleidsgericht – moet de connectie met andere onderzoeksdomeinen opzoeken, in het bijzonder met ruimtelijke planning. Afstappen van een puur ruimtelijke analytische visie door het incorporeren van tijd- en persoonsgebonden aspecten biedt de mogelijkheid een betere afstemming met andere beleidsdomeinen te bekomen. Ten slotte moet transportbeleid zich sterker richten op participatie en communicatie om zo een billijkere verdeling van de voordelen gegenereerd door transportsystemen te verkrijgen. Het conceptuele kader in samenspel met de casestudies zoals voorgesteld in dit proefschrift tonen het nut aan van persoonsgebaseerde bereikbaarheidsanalyse in het beantwoorden van mobiliteitsvraagstukken over billijkheid. Niettegenstaande moeten deze stellingen bekrachtigd worden door het vertalen van de theoretische achtergrond naar in de praktijk uitgewerkte proefprojecten. Dit is enkel mogelijk door participatie met de verschillende stakeholders die bereikbaarheid in de ruimte en tijd beïnvloeden en vormgeven. Toekomstig bereikbaarheidsonderzoek moet de voorgestelde werkvelden in rekening brengen om zo de geprojecteerde beleidsaanbevelingen op een correcte wijze te kunnen beantwoorden.

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Chapter 1: Introduction

Man and his works exist in Space and Time, a statement so banal that it hardly seems worth mentioning. Yet the unfolding of Man's patterns over geographic space and through time is a fascinating thing to study, and once you have thought about the processes at work in these dimensions of human existence you can never wholly return to "pre-diffusion" thinking.

Peter Gould, 1969

This chapter is primarily adopted from the following book chapters:
Fransen, K., Deruyter, G., De Maeyer, P. (2015). Concepts, Reflections and Applications of Social Equity: Approaches to Accessibility to Primary Goods and Services in the Region of Flanders, Belgium. In Adaptive Mobility : a New Policy and Research Agenda on Mobility in Horizontal Metropolises, ed. Luuk Boelens, Dirk Lauwers, and Frank Witlox, 17–44. Groningen: InPlanning.
Fransen, K., Farber, S. (forthcoming). From place-based to person-based accessibility – a three-dimensional framework for measuring transport equity. In Measuring Transport Equity., ed. Karen Lucas, Karel Martens, Floridea Di Ciommo Ariane Dupont-Kieffer.

Abstract

This first chapter serves as a general background and introduces the reader to the concepts of mobility and accessibility. The author aims to highlight how the concept of accessibility is better suited to address demand-driven transportation models, as it goes beyond merely providing mobility to the transport system users. In both scientific research and policy support, aspects of mobility and accessibility – or even transportation in general – are often considered from a purely spatial point of view. This leads to an incorrect representation of the actual situation, as temporal and personal restrictions strongly impact an individual's level of accessibility. Resultantly, transport policies are considered to possibly generate inequitable accessibility effects that favor certain population groups above others. Herein, the aspect of fairness of the transport system and its users is highly complex. The hypothesis is that person-based space-time accessibility measures are more suitable for equity appraisal than place-based measures and allow researchers or policy makers to address policy issues that cannot be addressed by using purely spatial accessibility measures.

1.1 Background

1.1.1 Defining accessibility: a widely applied yet slippery notion

Mobility defines a geography of opportunities as it allows users to access locations, services and people beyond their immediate surroundings. It is important to distinguish the concept of mobility from the concept of accessibility. Mobility primarily focuses on the ease of moving, whereas accessibility delineates the actual potential to participate in out-of-home activities. As a result, accessibility is a complex concept with a multitude of foci. Although the concept of accessibility is deeply rooted in the research domains of transport geography and planning (Neutens, 2015), the definition of accessibility greatly depends on the context, ranging from social equity studies to transport and economic expansion issues. The difficulty of finding an operational definition of accessibility is well stipulated by Gould, who said: “Accessibility [...] is a slippery notion [...] one of those common terms that everyone uses until faced with the problem of defining and measuring it” (Gould, 1969, p.64). According to Hanson (1995), accessibility is "the number of opportunities, also called activity sites, available within a certain distance or travel time" (Hanson, 1995, p. 4). Ingram (1971) used the following definition: “Accessibility may loosely be defined as the inherent characteristic (or advantage) of a place with respect to overcoming some form of spatially operating source of friction (for example, time and/or distance)” (Ingram, 1971, p. 101). A third definition is found in Morris et al. (1979): “Accessibility has generally been defined as some measure of spatial separation of human activities. Essentially, it denotes the ease with which activities may be reached from a given location using a particular transportation system” (Morris et al., 1979, p. 91). In essence, accessibility refers to the relative ease by which the locations of activities - such as work, shopping or health care - can be reached from a certain location and by using a given transport system. On the one hand, it varies across space, because it is affected by where the activities or services (supply) and the people (demand) are located. On the other hand, accessibility also varies over time, because supply and demand as well as the transport system are time-dependent (Luo & Wang, 2003; Neutens, 2015). In sum, the concept of accessibility can be perceived as the opportunity for individuals or groups to participate in a desired activity at a preferred location and at a chosen time.

In fact, accessibility is a multi-faceted concept that involves five dimensions: affordability, acceptability, accommodation, availability and geographic accessibility. These dimensions can be classified in two classes: spatial (geographic accessibility and availability) and non–spatial (affordability, acceptability and accommodation) (Penchansky & Thomas, 1981). In the spatial class, geographic accessibility can be defined as the relationship between the locations of supply and demand, taking into account the distance and the client's transportation resources and time budget. For example, if there are no pharmacies located within walking distance of a bus stop, they can only be accessed by car-owners or people who live nearby. Availability is the second spatial dimension and concerns the relationship between the volume and type of existing services and the client's volume and type of needs. Geographic accessibility and availability are often considered as one, and grouped under the denominators 'spatial accessibility' or 'accessibility'. In the non-spatial class, affordability denotes the relationship between the cost of a service and the clients' income or ability to pay. Acceptability refers to the relationship between the clients' attitudes about personal and practice characteristics of existing providers including gender, age, location, education, religion, etc. as well as the provider's attitude about personal characteristics of the client. A common example is found in shopping behavior. A store can be attractive for one person because the goods are priced low and of good quality, while another person can have issues with the store's hygienic condition and, as such, prefers to pay more for the same quality in another shop with higher hygienic standards. Finally, the term accommodation is understood as the relationship between how the supply resources are organized and the clients' capability to accommodate to these factors, such as the office hours of a service, and the clients' perception of their suitability (e.g., one's ability to get good medical care when needed). The non-spatial factors influencing the overall accessibility are often highly correlated. For example, neighborhoods with low educational attainment tend to have high unemployment rates and low income levels (without taking into account complex mechanisms such as upwards mobility or social and cultural capital) (Dai & Wang, 2011; Penchansky & Thomas, 1981).

Another classification of access to services is the potential access versus the revealed (realized) access. Revealed accessibility focuses on the actual use of the service, whereas potential accessibility signifies the probable entry into the service, but does not ensure the automatic utilization of the offered services (Khan, 1992; Luo & Wang, 2003). The ability to participate in out-of-home activities is closely related to one's well-being. An example of where potential access will influence policy is the issue of the ageing of the population. To face the ageing population in Flanders in the future, it is necessary to take action at the present. Based on demographic statistics, it is possible to calculate the number of elderly people in need of a retirement home in the short and medium term. The dimensions of the services (in the example, number of available rooms in homes for the elderly) can then be adjusted in response to the potential user dimensions. This means that potential access is offered to potential users. Potential access thus means probable entry into the retirement home system. However, it does not signify the automatic occupancy of the total number of rooms made available. The actual utilization is susceptible to a lot of factors (barriers or facilitators) depending on both the service and the users, such as the quality of the rooms, the cost, other services that may expand (i.e. home-based care), the retirement benefits, the family situation, etc. When the facilitators are preponderant to the barriers, the service will be utilized and realized access is achieved (Khan, 1992; Luo & Wang, 2003). While the concept of potential access is likely to be used in planning processes, the concept of realized access is often applied to evaluate existing systems.

The degree of fairness of access to these opportunities is an even more complex matter. Van Wee and Geurs (2011) highlighted three primary ethical theories that form the guiding principles for transportation equity: utilitarianism, egalitarianism and sufficientarianism. The utilitarianism approach states that an equitable distribution is achieved when the net benefits outweigh the costs and, therefore, is often applied to analyze and evaluate transport projects and plans (Rock et al., 2014). In other words, justice is done when the total amount of utility is maximized (Geurs and van Wee, 2004). Consequently, the distribution of these benefits is not taken into consideration. An egalitarian approach answers this shortcoming by introducing a sense of fairness by broadly stating that all people are to be treated equally. Nevertheless, this general view on justice does not consider specific needs and does not fully answer the question of who gains the benefits and who bears the costs. Sufficientarianism focuses on the degree that people can meet their particular needs sufficiently and states that priority should be given to improve the well-being below a certain threshold (Rock et al., 2014). This would, however, imply that small benefits for someone below this threshold are prioritized above benefits for larger groups, even though this choice would bring more people below that threshold. In addition, determining this cut-off value has proven to be a difficult task and seems practically impossible to justify. Martens et al. (2014) delineate prioritarianism as an expansion to sufficiantarianism, as it states that benefits matter more the worse off the person is to whom these benefits accrue. Contrary to sufficientarianism, the concern is not absolute: large gains for well-off people can outweigh small gains for worse-off individuals. The prioritarian approach has become an important focus of transport-related social equity studies.

1.1.2 Shaping mobility: the locational paradox

Urban environments are generally known for their high built density and their elevated number of and variation in facilities within walking or biking distance. Cities bear enormous potential for using their efficient layout and the proximity of amenities to maximize accessibility. Consequently, they have risen as pre-eminent spaces for initiatives to counteract the overall car dominance with more sustainable alternatives. In 2015, both Ghent and Brussels have reimagined their mobility plan to phase out cars and create more opportunities for cycling and walking. Car-free streets, hindrance of car flow between different neighborhoods and stronger restrictions in maximum drive speeds are becoming indispensable in cities' mobility policies. Recent ambitions are no longer only policy-based, more often citizen initiatives and organized movements arise that aim to improve the quality of life of the street, neighborhood or city they live in. "Cycling School Leuven" (*Fietsschool Leuven*), for example, annually teaches over 100 adults to safely ride a bike in the city of Leuven, with the ambition to provide a satisfactory substitute to car transportation. In Ghent, volunteers of the Lab van Troje-network aid the residents of dozens of streets to temporarily convert them to car-free zones with space for greenery, cohabitation and encounters. Another example is the project "Elderly as Public Transport Ambassadors" (*Ouderen als Openbaar vervoer-ambassadeurs*) in the regions of Flanders and Brussels, where elderly people provide information to contemporaries on how to use the public transport system, in order to overcome barriers such as the complex time schedules or the often cumbersome mechanisms of ticket purchasing. This type of qualitative investments contribute to putting a halt to the great migration from the city centers to suburban and rural areas that peaked in the second half of the 20th century as a result of the increased wealth and automobile ownership and usage.

Paradoxically to the apparent advantages of living in a city, suburban and rural areas remain the most favorable living location for households willing to trade in proximity and vivacity for tranquility and spaciousness, at the cost of car ownership and longer commutes.

The outer city neighborhoods and suburbs combine the vicinity of the city center's goods and services with the peace and quiet of living outside the city core. As the city's scale remains small, commutes, leisure trips and social visits are characterized by short distances, which are often still possible to bypass by bike (the emergence of the electrical bike has even further increased the radius by bike) or on foot. The accessibility to daily needs such as employment, health care or education remains relatively high, even for households with a lower mobility. However, as the distance to the city center increases, so does the transport dependency. Facilities are more distributed and thus harder to reach, and the range of options rapidly diminishes. Additionally, public transport stops that commonly radiate peripherally from the city center, become a rare characteristic in the rural fabric. Road layouts are no longer focused on pedestrians' and cyclists' safety, as sidewalks and bike lanes make way for car-oriented infrastructures that ameliorate the efficiency of travel by car. These transitions culminate in the most remote areas, frequently distinguished by ribbon development along the roads connecting city centers.

The dichotomous relationship between the urban and rural environment is reflected in transport policy that emphasizes on – especially car-based – mobility rather than on accessibility. From an environmental and economical point of view, this dichotomy between urban and rural mobility is believed to be transmitted in the degree of sustainability, as longer commutes lead to more transport-related externalities. To prevent these externalities from manifesting, policies often strive to minimize the environmental and economic effect of the growing mobility in order to enhance sustainability, and discussions on these topics are a fundamental component of the daily debates. Governmental sustainable development strategies are at work in the cross-section of the economic and environmental domain. These debates, however, fall short to the question of how the complexities of the existing and evolving society's travel behavior are incorporated into the decision process of actions that lead to this gain in mobility. Consequently, this growth should not be compensated after the decision process, but it should be countered by including a more sustainable provision to the population's complex mobility needs into the decision process. Boussauw and Vanoutrive (2015) rightfully indicate that the development of a transport system that is overall less environmentally harmful does not automatically contribute to a more just and socially substantiated configuration. This line of reasoning rises beyond the classic vision on mobility, as the social domain of sustainability is incorporated into the equation (Fig. 1.)

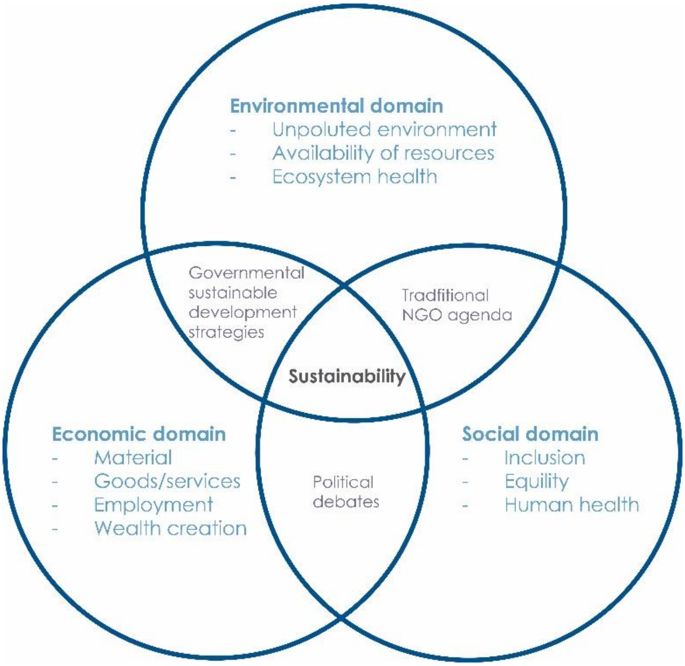

Fig. 1. The domains of sustainable development (Reeves, 2005)

The concepts of 'transport', 'travel' and 'traffic' play a pivotal role in monitoring and defining the sustainability of a transport system (Gillis et al., 2016). Herein, transport is the overarching terminology that encompasses everything related to the transfer of goods or people from one location to another. Travel, is a more 'active' concept, which entrails the user's need and ability to move from one location to another to participate in an activity. Finally, traffic is the actual movement of vehicles transmitted across a road network or infrastructure, and can be considered as the product of transportation. These three concepts are referred to as the markets or arenas where different actors interact with various types of demand and supply. Therefore, they are relevant for academic research as they simultaneously act as the main indicators of the mobility system.

There is a wide recognition that transport policies are able to generate spatially as well as temporally uneven accessibility effects that give preference to certain population groups above others. Nonetheless, policies are capable of simultaneously striving for a more equitable distribution of transport services amongst the population. Herein, social disadvantages related to particular mobility needs have a strong link with the transport disadvantages that occur because of the specific transport system's characteristics. Combining both practical and theoretical research on social exclusion and transport poverty enables researchers to join forces with policy makers and analysts in order to pinpoint a wide range of issues as accurately as possible. Nevertheless, measuring transport-related social exclusion has been a difficult matter to address. The region of Flanders, for example, has adopted a clear-cut stance towards combatting social disadvantages, as it is one of the only regions in the world where the right to basic provision of public transport is granted by law in the decree *Personenvervoer* (*Decreet betreffende de Organisatie van het Personenvervoer over de Weg, B.S.*, August 21, 2001). This right is defined as the right to basic mobility (*Basismobiliteit* (*Besluit van de Vlaamse Regering betreffende de Basismobiliteit in het Vlaamse Gewest, B.S.*, January 23, 2003)) and is formulated as having spatial access to a minimum level of public transport service irrespective of the location of residence. However, as this decree defines maximum distances to transport stops and minimum frequencies at these stops, it answers to social disparities in access to the public transit system (accessibility of the transit stops) rather than facilitated by that transit system (accessibility through the transit system). It does not determine which places or services a person could reach at a given time and, as such, portraits mobility rather than accessibility. Furthermore, a gain in mobility only leads to a higher accessibility if people can satisfy their primary daily needs. Recently, understanding the ways in which inadequate mobility can contribute to social disadvantage and isolation has been brought to the forefront of the transport policy agenda (Fransen, et al., 2015). The right to basic mobility as constructed in 2001 by the Flemish government, for instance, is currently reformulated as the right to basic accessibility (*Basisbereikbaarheid*). Hence, this revision will additionally aim to guaranty access to specific location types by providing a need-based instead of a provision-based model.

1.1.3 Modeling accessibility: from place-based to more sophisticated person-based measures

Accessibility to vital activities such as employment, education or health care has an important impact on an individual's level of embeddedness in society and, therefore, his/her quality of life. Modeling this accessibility has a long history with a trend towards increasingly sophisticated measurements. More detailed accessibility analyses enable to better determine who has the strongest claim when resources are scarce and, therefore, further unravels the key role transport may play in ensuring an equitable distribution of opportunities. Based on their complexity, methods for measuring accessibility can be categorized in at least four groups. The first group consists of methods in which accessibility is measured at the level of spatial boundaries, mainly administrative districts. 'Provider to population ratio' (PPR) is the most popular method in this category and is derived from dividing the number of facilities (supply) by the number of inhabitants (potential demand) located within a zone of a zoning system. An important limitation of these 'container-based' metrics is the assumption that facilities outside the predefined areal unit are inaccessible and that those within the unit are equally accessible to all people within that areal unit. As the same level of accessibility is allocated to all inhabitants of a zone, these methods do not factor in the difficulties related to the spatial distribution of both supply and demand within that zone and ignore competition between suppliers and consumers (Huff, 1963, 1964). However, these methods are often used in spatial policy decision making because such metrics are easy to calculate, do not always require Geographical Information Systems (GIS) tools and are intuitive and readily understood by policy makers (McGrail & Humphreys, 2009; Neutens, 2015). An example of PPRs used in Belgium can be found in IMPULSEO, a system that awards financial assistance to physicians settling in shortage areas based on the calculation of the PPR per physician zone. Nevertheless, research shows that this only offers a very crude representation of accessibility to primary health care, because physician zones cover too large a geographic area (Dewulf et al., 2013).

Methods belonging to the second group are slightly more complicated than PPRs, however they also produce easily interpretable values, and are easy to understand and implement using popular off-the-shelf GIS software. Well known methods are 'travel impedance to nearest provider', also called 'closest facility' function (CF) and 'average travel impedance to provider'. Herein, travel impedance or travel cost can be expressed as a distance, a travel time, or an amount of money and is often used to define the size of the catchment area of a population or a service. Numerous accessibility measures use the concept of catchment areas of which the size is defined by the threshold travel impedance or the maximum cost a person is willing to spend on one trip. As a consequence, the distance is often not introduced directly in the accessibility calculations. Instead, the threshold travel distance will be calculated and then used as input for the network calculations given a certain maximum time limit, a transportation mode, a transport network and speed limitations inherent to this transportation mode or to this network. The advantage over PPRs is that services in other zones are also considered, however, in the CF, the competition between services is still not accounted for. Therefore, the measure is primarily useful in rural areas characterized by a low availability of services. The average-travel-impedance-to-provider method is more suitable for analysis in urban environments, as it considers all the services or a predefined maximum number of the closest services in the research area. This method introduces the competition between services into its calculations. Taking into account the demand side, however, requires more advanced models. Variations to these basic principles are applied in different case studies (Apparicio et al., 2007; Apparicio et al., 2008).

The third category comprises the more complex gravity-based and cumulative-opportunity measures that partly overcome the limitations of the methods described above. They rely on three elements: the demand or population location, the service locations such as shops, physicians, or schools, and an impedance function (travel impedance) to reduce the number of opportunities in function of the distance or effort that needs to be overcome (Delamater, 2013). They deliver a combined indicator of accessibility and availability and can provide accessibility measures for both urban and rural areas. Gravity models attempt to represent the potential interaction between any population point and all service points within a cut-off value, discounting the potential with a mode-dependent impedance decay function. To be successful, these functions need to be fine-tuned for each new study to reflect the true impedance at that point in time and space. Cumulative-opportunity measures on the other hand, integrate the impedance by excluding opportunities beyond a cut-off value. The simple gravity-based model has two main problems. First, the calculated values are not intuitive for policy makers, who prefer to think of spatial accessibility in terms of PPRs or simple distances. Second, it only models supply. There is no adjustment for demand or for the competition between services (Luo & Wang, 2003). Over the years, several enhanced methods were developed based on the gravity model. Some of these sub-types are extensively documented in literature.

The floating catchment area (FCA) family of metrics is a widely applied method and is based on gravity models (Luo and Qi, 2009; Wan et al., 2012; Delamater, 2013; McGrail and Humphreys, 2014). FCA metrics incorporate the interaction among supply, potential demand, and travel cost in their characterization of spatial accessibility. These metrics allow the containers to "float" as travel buffers or catchments and are based on the travel impedance from the facility and/or population locations. They also offer detailed variations within large administrative entities. Therefore, they offer a more realistic approach of accessibility than the traditional container-based regional availability measures (first category). The shape and size of the catchment area depend on the density of the transportation network, and their location in it. Unlike general gravity models, the FCA metrics provide an output in a highly interpretable supply-to-population ratio (e.g., number of physicians per person) and was, among others, applied to calculate accessibility to primary health care (Luo, 2004; Luo & Wang, 2003). A disadvantage of the FCA method is that it does not account for the competition between services in case of overlap between service areas. This limitation is overcome by the two-step floating catchment area (2SFCA), which is a favored method for the assessment of accessibility to health care (McGrail & Humphreys, 2014). The 2SFCA was subject to further modifications, some of them tailor-made solutions to a specific accessibility issue. The most well-known are the enhanced 2SFCA (E2SFCA) and the kernel density 2SFCA (KD2SFCA), which improve the calculations by introducing travel impedance decay functions in function of the distance to the center of the catchment area, meaning that locations near the center are more accessible than locations situated at the edges (Dai & Wang, 2011). Another example is the three-step floating catchment area (3SFCA) which also accounts for the potential competition between services to avoid an overestimation of the demand when several services are accessible from one location (Bell et al., 2013; Wan et al., 2012).

The structural simplicity of place-based analysis measures that define accessibility as physical separation allows for more complex embellishments. Instead of focusing on the various dimensions of accessibility, maximizing the proximity of activities and providing mobility to activity users are currently considered as the leading notions in countering the dispersion of functions in the built environment: on the one hand, activities should ideally be within close range or, on the other hand, inhabitants are considered to be sufficiently mobile to reach a large number of activities. However, these are provision-driven concepts that fail to address the actual demand and strongly rely on spatial restrictions. The time geography approach was introduced by Torsten Hägerstrand as a claim for a general geographical perspective where the concept of space is broadened by societal and environmental aspects related to time (Hägerstrand, 1970). This approach allows researchers to reveal relationships that are unidentifiable when studied in isolation from its given environment and context, for example in the domain of transportation (Lenntorp, 1999). In addition, individual behavior and experience related to contextual influences create spatial and temporal uncertainty. Kwan (2012) refers to this issue as the Uncertain Geographic Context problem, which notes that no researcher has full knowledge of the true causally relevant context. The shortcomings attributed to the use of purely place-based methods have thoroughly been addressed in the domain of transportation. Incorporating temporal and individual restrictions allows researchers to approach transport-related issues in a more detailed way, therefore, addressing the actual distribution of benefits – and related transport disadvantages and aspects of social equity – more accurately through an accessibility framework. The focus on person-based accessibility enables to evolve to more demand-driven transportation models that aim to align demand and provision as much as possible.

While the first three categories are predominately place-based measures, the fourth category consists of person-based measures or a combination of both. Place-based accessibility measures are particularly suited to examine changes in the proximity of services to the homes or workplaces of individuals or modifications of the transport network. All these measures tend to use the home or workplace as a static substitute for an individual. They ignore the many trips that originate from the work location (such as noon errands and childcare), other anchor points, and the multi-linked trips. Furthermore, they do not account for accessibility limitations as a result of social inequalities caused by language, gender, financial situation, mobility, etc. or individual-based needs (Miller, 2007; Neutens, 2015). Moreover, these accessibility indicators ignore the fact that accessibility is time-dependent and that both supply and demand fluctuate over time, e.g. day and night rhythm, daily routines, travel time, public transport schedules and traffic congestions (Delafontaine et al., 2011; Neutens et al., 2010). When temporal changes are made to the service provision (e.g. by changing opening hours), spatio-temporal accessibility levels will fluctuate, which may lead to the exclusion of certain groups within the population from participating in specific activities (Casas, 2007). In fact, the actual accessibility levels will constantly fluctuate during daily or weekly cycles. These fluctuations derive in part from variations in operating hours of services and facilities as well as from the individuals' commitments or fixed activities that bind them to particular places at specific times of the day, e.g. workplace, childcare, shopping, sleeping (Schwanen & de Jong, 2008; Zandvliet &

Dijst, 2006). Today's lifestyle implies that using information about the distribution of the stationary, night-time population across street addresses or zones and the implicit assumption that (adult) members of that population can access services at any time of the day, as the basis for the evaluation of changes in service provision have become increasingly problematic (Neutens et al., 2010).

Person-based accessibility measures rely on the characteristics of the transportation system as well as on detailed observations of an individual's activity schedule (Neutens et al., 2010). A very recognizable situation in which spatio-time accessibility measures (STAs) can be used to improve accessibility on an individual level is comprehensively narrated by Schwanen and de Jong (2008) in the article "Exploring the juggling of responsibilities with space-time accessibility analysis". In this article the story of a highly educated mother who has to reconcile fixed employment times, chauffeuring her son to childcare, and a lengthy commute via congested highways is used to explain the benefits STAs have over the traditional place-based measures. The case study shows how STAs allow analysts to evaluate if, and to what extent, individuals can benefit from proximity to services. Nonetheless, the number of empirical studies of space-time accessibility that explicitly consider the effects of open hours on opportunities is limited to date.

Recently, researchers have succeeded in introducing not only spatially related parameters, but increasingly also temporal and person-based parameters into the calculation of accessibility measures, thanks to the increased computational power of GIS and the availability of individualized activity and travel data. Instead of a measure of potential accessibility, it is now possible to determine revealed or realized accessibility for different cohorts of people. This leads to more accurate and realistic assessments of changes, variations or gaps in accessibility, but also implies more complex methods and results that are difficult to interpret, which is probably the main reason why most policy decisions are still based on the simple and intuitively interpretable, yet not adequately accurate PPR methods.

Although policy makers have historically paid little attention to the exploration of these complex analysis methods, there has been a shift within the planning and transport fields towards a focus on measures that aspire to attain a just and equitable distribution of opportunities. The structural graph in Fig. 2 indicates the necessity of extending place-based accessibility methods by incorporating temporal and individual restrictions. A large number of factors influencing accessibility go beyond the merely spatial dimension and, although these restrictions are active at different levels, they are strongly interrelated.

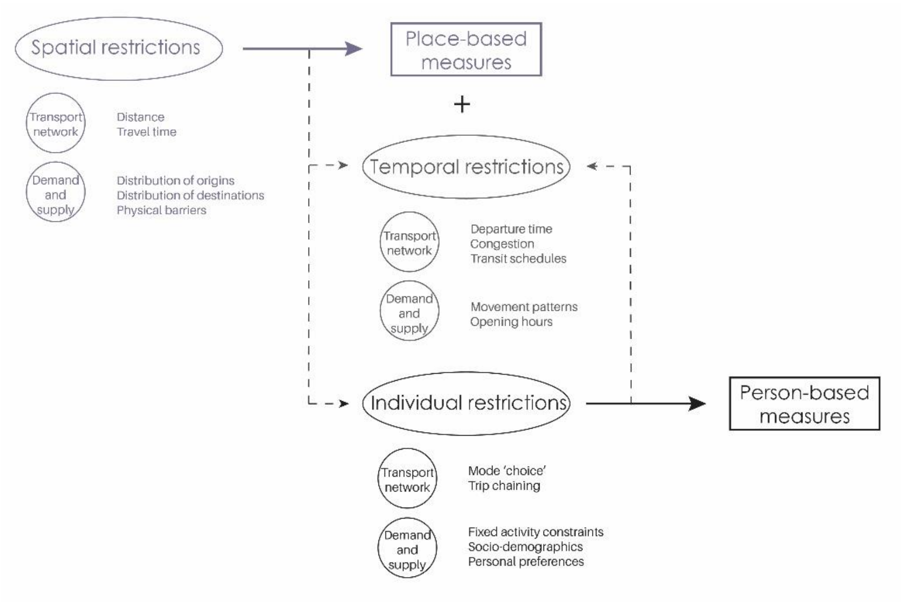

Fig. 2. From place-based to person-based models: the importance of all three dimensions

Distance or travel time, for example, from a place-based point of view are a very static interpretation of an individual's travel cost along the transport network. Temporal restrictions such as public transport operating times influencing availability or higher travel times due to congestion can have a strong impact on the actual travel cost experienced by the individual. Nonetheless, incorporating spatial and temporal restrictions in space-time accessibility measures (STA) primarily allows to examine accessibility on a (dis)aggregated level. Due to their aggregate level of analysis, impersonal STA hinder important claims on equity issues at the individual level. A large number of person-based factors additionally impact an individual's level of accessibility. Car ownership, for example, delineates the ability or necessity to use a certain transport mode, which in turn impacts the departure time, movement pattern or affordability and, resultantly, the general travel cost for that specific person. Another example is the age of the individual, which determines a person's dependence on other family members to reach places. As such, these individual characteristics are necessary for person-based STA because they pinpoint differences in accessibility levels and prove to be vital in assessing the equitability of the distributional benefits that can only be examined on the individual level.

1.2 Problem statement and research questions

The introduction of the proposed dissertation indicates that current place-based accessibility measures fail to correctly address transport-related equity issues. More elaborate person-based, space-time accessibility measures that – in addition to spatial barriers – take into account temporal and personal restrictions are needed to adequately assess the equitability of a transport system. **The hypothesis is that person-based space-time accessibility measures are more suitable for equity appraisal than place-based measures and allow researchers or policy makers to address policy issues that cannot be addressed by using purely spatial accessibility measures.** The typical urbanized, car-oriented Flemish landscape provides an interesting case study area to assess the equitability of the transport system by using (person-based) space-time accessibility measures. Therefore, the following research questions (RQ) are constructed:

- RQ1: What benefits do geographic information systems (GIS) provide to person-based space-time accessibility analysis?

GIS provide users with the opportunity to examine the relationship between different layers of information. Often considered as the main tool for spatial analysis, GIS have developed quickly during the last decade and have constantly extended their functionalities to go beyond the spatial dimension. More elaborate extensions (e.g., Network Analyst or Add GTFS to a Network Dataset by Esri's ArcGIS) allow users to introduce and analyze temporal information. The increasing functionalities in combination with performance improvements have additionally allowed GIS to handle larger datasets (e.g., individual information) more swiftly. This dissertation assesses the benefits GIS bring in evolving from place-based to person-based accessibility analysis by applying GIS-based space-time analysis on an increasingly detailed level in the various case studies.

- RQ2: To what degree do temporal and personal restrictions facilitate (existing) transport disadvantages?

The Social Exclusion Unit set up in 1997 has linked transport to social exclusion through the concept of accessibility planning. The resulting report has convinced researchers worldwide to assess social exclusion as a result of transport problems. Fig. 3 shows that a large portion of factors influencing both transport and social disadvantages are related to temporal and personal restrictions (e.g., poor public transport services or low income). Therefore, it is necessary to go beyond purely spatial analysis in order to address these disadvantages, and more specifically pinpoint manifestations of transport poverty and social exclusion. In the proposed case studies, temporal and personal restrictions are a vital part of the accessibility analysis, as the primary goal is to assess (transport) disadvantages related to the transport system(s).

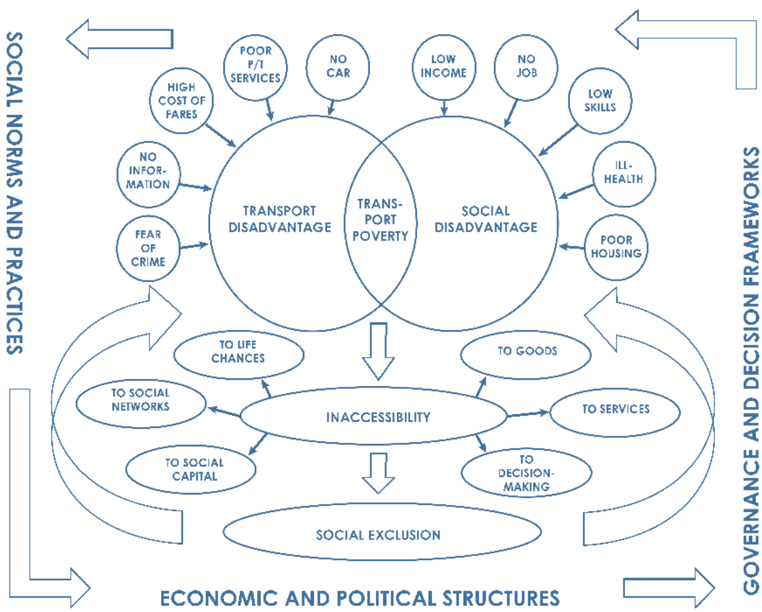

Fig. 3. Transport poverty as the interaction between social and transport disadvantage (Lucas, 2012)

- RQ3: Is access to opportunities distributed equitably in Flanders, Belgium? If not, what types of disadvantages exist and who is affected by them?

In continuation of the second research question, the case studies primarily focus on highlighting the degree and type of disadvantage that is generated due to an uneven distribution of benefits generated by the transport system. Herein, the car-oriented and strongly urbanized region of Flanders (Belgium) is the primary area of research. The rise of automobile usage in the post-World War period has strongly shaped the Flemish landscape, and more specifically, Flemish urban planning policies. This has led to and confined the current dispersed land use patterns, which brings about great barriers to its inhabitants' accessibility to (primary) services. Although recent planning and transport policy efforts aim at countering these obstacles, overcoming the limitations posed by the current land use fragmentation and the related ingrained travel behavior proves very difficult. The proposed dissertation addresses this research question by providing case studies that examine accessibility to primary services (e.g., health care, employment, etc.) for the study area of Flanders. Moreover, the case studies aim to highlight in detail who actually benefits from the way mobility and accessibility are currently envisioned by policy.

- RQ4: Can policy support based on an accessibility framework assist in countering social exclusion?

In line of the second and third research question, the dissertation links to existing policies in the concluding chapter and, more specifically, the degree to which policies aim at counteracting existing inequities. Herein, a stronger link with academic research as well as a better cooperation between the various other policy domains can enable transport policy to answer issues of exclusion more correctly. In the case studies, accessibility was considered as the most suitable tool to highlight transport disadvantages. Analogous to the current shift from basic mobility to basic accessibility in Flanders, for example, the case studies support the use of accessibility analysis, as it allows users to incorporate a broader range of factors that determine a person's opportunities.

The proposed dissertation addresses these four research questions with five case studies – four in Flanders (Belgium) and one in the Wasatch Front Region, Utah (US). These case studies gradually explore the evolution from place-based to person-based, space-time accessibility measures by incorporating additional restrictions into the analysis. Chapter 2 introduces the transition away from place-based accessibility measures by comparing a commonly applied method with an adaptation that includes the typical movement pattern of commuting into the equation. The case study indicates that comprehending the temporal nature of demand (and supply) has the ability to provide different results than the purely spatial, home-based representation of accessibility. Subsequently, Chapter 3 further enables the explorations of the use of space-time accessibility measures by incorporating the temporal variability in the transport network. Especially for public transport, temporal restrictions strongly shape the distributional benefits of the transport system. This case study highlights areas characterized as transport gaps if the transit provision failed to address the specific public transport needs for individuals residing in this area. Both case studies in Chapter 2 and 3 note the importance of applying time-based accessibility measures when assessing the equitability of the distributional benefits generated by a transport system – be it car or public transport. Chapter 4 deploys a space-time accessibility measure to determine the impact of the mode choice on accessibility. Incorporating car ownership on a zonal level into the equation allows to assess each area's multimodal accessibility to job openings. Chapter 5 and 6, however, further elaborate on the temporal variability, but extend beyond the aggregated nature of the previous case studies by additionally incorporating personal restrictions into the analysis. Chapter 5 applies a person-based accessibility measure based on individuals' activity diaries to determines the spatiotemporal accessibility to discretionary activities. The person-based measure is compared to a place-based accessibility measure to determine both methods' applicability in determining activity participation. This idea is complemented by the disaggregated space-time accessibility measure presented in Chapter 6 that focuses on the demand and supply side by incorporating personal preference and competence related to the demand side as well as characteristics related to the supply side into the analysis. In the last two cases, the space-time accessibility is measured on an individual level, and provides a solid base for equity appraisal as well as policy support. The use of GIS is a constant denominator in every case study, and the more complex the case studies grow, the more demanding the GIS models and data requirements become. More detailed analysis, however, enables to perform equity appraisal for the various case study areas more accurately.

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Chapter 2: Commuter-based accessibility to daycare centers in East-Flanders

The way we currently envision mobility is outright destruction of space and time. If we are constantly moving from location A to location B, should we not try to plan both locations right next to one another?

Luc Eeckhout, 2016
(De Standaard)

This chapter is adopted from the following journal article:
Fransen, K., Neutens, T., De Maeyer, P., Deruyter, G. (2015). A commuter-based two-step floating catchment area method for measuring spatial accessibility of daycare centers, *Health & Place*, 32, pp. 65-73,

Abstract

This paper puts forward a commuter-based version of the two-step floating catchment area (2SFCA) method, which has gained acceptance in studies on spatial health care accessibility. Current implementations of the 2SFCA method are static in that they consider centroid-based night-time representations of the population. The proposed enhancement to the 2SFCA approach addresses this limitation by accounting for trip-chaining behavior. The presented method is illustrated in a case study of accessibility of daycare centers in the province East Flanders in Belgium. The results show significant spatial differences in accessibility between the original and commuter-based version of the 2SFCA (CB2SFCA). They highlight the importance of giving heed to more complex travel behavior in cases where the need for detailed accessibility calculations is apparent.

Keywords: daycare center, accessibility, two-step floating catchment area method, GIS

2.1 Introduction

Equitable provision of health resources is a key priority to health professionals and policy makers worldwide. To pinpoint regions where to increase or cut down service provision, researchers have proposed various methods to identify underserviced or overserviced areas. These methods range from simple provider-to-population ratios to more advanced gravity-type metrics that trade off size and/or quality of the available services against the travel costs to reach them. One method that has gained traction recently is the two-step floating catchment area (2SFCA) method (Luo and Wang, 2003). In the 2SFCA method, catchment areas of a particular size float on both supply and demand points. Resultantly, this metric expresses how many services with varying degrees of capacity, and local demand are available to a certain population. The method is conceptually appealing because it regards capacity restrictions as well as local competition and, in contrast to common provider-to-population ratios, it allows for cross-border service-seeking behavior. The approach is also interesting from a practical point of view as it is easily interpretable and communicable, and is relatively easy to implement with conventional off-the-shelf Geographic Information Systems (GIS). In recent years, several modifications and extensions have been suggested to the original approach (Bell et al., 2013; Mao and Nekorchuk, 2013; Ngui and Apparicio, 2011), and the method has been applied in a wide range of domains, including accessibility to primary health care services (Dewulf et al., 2013), public transport stops (Langford et al., 2012) and food outlets (Dai and Wang, 2011).

Despite their growing popularity, the 2SFCA metrics cannot account for the impact of individual mobility on access to services because they generally consider a single reference location. Furthermore, they do not allow for interpersonal heterogeneity in activity-travel patterns (Neutens et al., 2012). Due to these limitations, degrees of accessibility are assigned unjustly. Together with Guagliardo (2004), Miller (2007), Apparicio et al. (2008) and Kwan (2009), this paper argues the need for temporally integrated perspectives on health service accessibility dealing with behavioral and mobility aspects. A commuter-based approach of modeling spatial accessibility is put forward by regarding commuting behavior from the home to the work location. Hence, this is a first step towards considering complex person-based and space-time constraints.

The developed method is applied in a case study of accessibility to daycare centers in the province of East Flanders, Belgium. This case is apposite for three reasons. First, the case provides a clear example of destinations frequently combined with other activities in a trip chain. This is particularly the case for work-related activities. A questionnaire drawn up by the Flemish agency of Child and Family notes that 22% of parents prefer a daycare situated on the way to work in order to be able to chauffeur their child. Second, the slow growth in daycare capacity is currently being outpaced by a rapidly increasing demand. Therefore, gaining detailed insights into the spatial mismatches between the supply and demand of daycare centers is sorely needed in (supra-)local policies. Third, apart from a few exceptions (Kawabata, 2009, 2010, 2011; Schwanen and de Jong, 2008), research concerning spatial accessibility of daycare services has garnered little scientific attention, relative to other health-related services such as primary care physicians (Luo and Qi, 2009), clinics (McLafferty and Grady, 2005), screening centers (Henry et al., 2013) or dental services (Horner and Mascarenhas, 2007). A combination of GIS software and Python scripting is used to automatize the spatial procedures of the proposed method.

This paper starts with a background section that discusses the importance of daycare provision and the scarce body of literature on access to daycare amenities. In section 3, the evolution from provider-to-population ratios toward floating catchment methods is briefly reviewed, as well as the latest contributions to the commonly applied 2SFCA method. Next, a commuter-based version of the 2SFCA method is proposed and illustrated. Section 4 provides information about the data, study area and implementation, and the results are reported in section 5. The paper concludes with a brief discussion and outlines avenues for future research.

2.2 Background

Adequate provision of daycare is seen as an important prerequisite of public health and quality of life (Baizan, 2009; Yamauchi, 2010). Nonetheless, the majority of major Flemish cities are characterized by a shortage of daycare capacity relative to the local demand. These capacity problems often force parents to rely on informal daycare by grandparents and relatives or to patronize daycare centers at greater distances. Capacity issues may differentially affect certain social strata and mainly impact those who cannot rely on their social network and/or have limited mobility resources. Because fees increase when the demand increases, low-income families are probably unable to pay for formal daycare facilities unless prices are regulated (Farfan-Portet et al., 2011). In countries where daycare is subsidized, its usage is more strongly driven by proximity instead of cost (Chiuri, 2000; Immervoll and Barber, 2006; Kreyenfeld and Hank, 2000).

Despite the importance and currency of the matter in various countries, literature on spatial deficits in access to daycare amenities is relatively scarce. Some studies superficially examined the accessibility to daycare centers as part of a broader study. Webster and White (1997), for example, analyzed the daycare accessibility in the context of labor-market participation among mothers in the UK, while Pearce et al. (2008) investigated accessibility to daycare centers in New Zealand in order to help explain deprivation. More detailed research examined the accessibility toward daycare to determine a spatial mismatch between supply and demand (Kawabata, 2009, 2010, 2011) or to illustrate the difference between positive and normative implementations of accessibility measures (Paez et al., 2012). In addition, Schwanen and de Jong (2008) applied space-time accessibility modeling to determine person-based accessibility of daycare facilities in an ethnographic analysis of how parents juggle employment and caregiving responsibilities.

There is a number of studies in the domain of health care that assess accessibility based on the combination of home and work location. The study by Salze et al. (2011), for example, indicated that accounting for both home and work-based accessibility for a commuting population leads to an overall increase in accessibility, yet this increase differs according to the urbanization level. The authors constructed an extended provider-to-population ratio model that additionally accounted for work-based accessibility and compared it to a general potential accessibility model. Another example is the study by Widener et al. (2013), which introduced commuting flows into a space-time accessibility measure to assess spatial access to healthy foods in urban regions. The results showed higher levels of accessibility when accounting for commuting behavior than when measuring access from home and highlighted the need for more nuanced calculations of accessibility. The introduction of commuting behavior into the analysis of access to daycare, however, has not been addressed in previous research.

2.3 Method

2.3.1 From provider-to-population ratios toward floating catchment methods

One of the most commonly applied methods to measure accessibility in health care studies is by means of provider-to-population ratios (PPRs). PPRs are derived from dividing the number of facilities (supply) by the number of inhabitants (potential demand) located within a zone of a particular zoning system. While PPRs are easy to calculate, do not necessarily require GIS tools or expertise and are intuitive and readily understood by policy makers (McGrail and Humphreys, 2009), they are also overly simplistic, primarily because they ignore the exact spatial distribution of both supply and demand, and ignore competition effects between suppliers and consumers (Huff, 1963, 1964). Moreover, PPRs do not regard variations in accessibility within bordered areas. In response to the latter shortcoming, a regional accessibility approach was formulated to consider supply and demand located in different regions with distance decay (Guagliardo, 2004; Yang et al., 2006). The basic gravity model is expressed as:

$$A_i = \sum_{j=1}^{n} \frac{S_j\, f(d_{i,})}{\sum_{k=1}^{m} P_k\, f(d_{ik})} \tag{1}$$

where A_i is the spatial access for location i, S_j is the supply capacity for facility j, P_k is the population size of location k, d_{ij} is the travel cost from location i to facility j, d_{ik} is the travel cost from location i to location k and n and m are the amount of supply sites and locations respectively. According to Kwan (1998), the three most applied forms of $f(d)$ are the inverse-power function ($f(d) = d^{-\beta}$), the exponential function ($f(d) = e^{-\beta d}$) and the Gaussian function ($f(d) = e^{-d^2/\beta}$), where β is the impedance coefficient indicating the extent of distance decay.

Although more sophisticated than traditional PPRs, the gravity model still determines accessibility based on a static representation of supply and demand in a zone. Therefore, it does not account for cross-border health care seeking behavior (Luo and Wang, 2003). To overcome this limitation, Luo (2004) proposed the two-step floating catchment area (2SFCA) method, based on the spatial decomposition idea by Radke and Mu (2000). It is a special case of gravity model, but it is more intuitive to interpret, regards local competition between services and incorporates geopolitical border-crossing (Guagliardo, 2004). In this method, accessibility in a census tract is defined as the provider-to-population ratio within its catchment area by using 'floating catchment areas' or windows rather than fixed geographical or administrative areas (McGrail and Humphreys, 2009). In the first step, the PPR R_j is estimated for each facility location:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k} \tag{2}$$

where P_k is the population of census tract centroid k within the catchment area, S_j is the supply capacity of facility j, d_{kj} is the travel cost from location k to facility j and d_0 is the threshold travel time for each facility site j. In the second step, the PPR is calculated for each census tract centroid by summarizing all PPRs from step one:

$$A_i = \sum_{j \in \{d_{ij} \leq d_0\}} R_j \tag{3}$$

where A_i is the accessibility for a population at location i, R_j is the PPR of a service site j within the catchment area of i, and d_{ij} is the travel cost from location i to facility j. There is a recurring interest in defining reasonable sizes for catchment areas and functions that represent distance decay behavior (Wang, 2012). A fundamental modification to the 2SFCA method is the enhanced two-step floating catchment area (E2SFCA) method developed by Luo and Qi (2009). This method augments the 2SFCA method by applying a distance decay function, thus overcoming the assumption of equal access within the service area. For this enhancement, weights are applied to different travel time zones to account for distance decay:

$$R_j = \frac{S_j}{\sum_r \sum_{k \in \{d_{kj} \leq d_0\}} P_k W_r} \tag{4}$$

$$A_i = \sum_r \sum_{j \in \{d_{ij} \leq d_0\}} R_j W_r \tag{5}$$

where W_r is the distance weight for the r^{th} travel time zone defined by the distance decay weight function capturing the distance decay of accessibility to facility j. In addition, McGrail and Humphreys (2009; 2014) further refined the E2SFCA by applying multiple catchments with increasing sizes relative to the varying remoteness of different types of rural areas.

Although the E2SFCA is more complete than previous methods, Wan et al. (2012) indicated that by failing to include the potential for competition, the healthcare-demand is overestimated for some facilities. They assumed that healthcare demand is influenced by the availability of other nearby facilities, as people's demand for that facility will decrease when adjacent facilities are also available. This effect of overestimation is amplified in areas where facilities are densely concentrated. In order to address this limitation, they incorporated a spatial impedance-based competition scheme in addition to the methodology outlined in E2SFCA. In the three-step floating catchment area (3SFCA) method, a travel-time-based competition weight is assigned for each population and facility pairing:

$$G_{ij} = \frac{T_{ij}}{\sum_{k \in \{d_{ik} \leq d_0\}} T_{ik}} \tag{6}$$

where G_{ij} is the selection weight between location *i* and facility *j*, d_{ik} is the travel cost from *i* to any facility *k* within the catchment and d_o is the catchment size. T_{ij} and T_{ik} are the specific pairwise weight values for *j* and *k*, respectively, based on the relative location of the facility in the system. Next, this selection weight is applied in the calculation of the demand of facilities:

$$R_j = \frac{S_j}{\sum_r \sum_{k \in \{d_{kj} \leq d_0\}} P_k W_r G_{ij}} \tag{7}$$

$$A_i = \sum_r \sum_{j \in \{d_{ij} \leq d_0\}} R_j W_r G_{ij} \tag{8}$$

According to Delamater (2013), all FCA metrics contain an underlying assumption of optimally arranged supply locations that exactly meet the needs of the population within the system. In other words, all supply opportunities are assumed available to the population, in spite of the configuration of facility and population locations within the study area. Also, a reconfiguration of the supply locations will not result in a different spatial accessibility for the overall study area because it is considered as a single, large container. However, no real-world system is truly optimal and reconfiguration of existing supply locations will affect the spatial accessibility of the overall system. Because of these limitations, the author indicated that the 3SFCA proposed by Wan et al. (2012) overestimated the role of competition in an applied setting. Therefore, he suggested a modified two-step floating catchment area (M2SFCA) method that discounts spatial accessibility based on the suboptimal configuration of facilities in the system. Consequently, accessibility and availability were combined into a single metric. Furthermore, the overall efficiency of spatial accessibility within the health care system can be described enabling quantitative comparison of large-scale health care systems.

Other cognate studies have further incrementally increased the realism of the 2SFCA by detailing the supply and demand side. The optimization method of Ngui and Apparicio (2011), for example, accounted for differentiation in supply and demand by applying weights based on the number of physicians working in each healthcare facility (supply) and the age of potential healthcare users (demand). Bell et al. (2013), for their part, introduced different spatial and aspatial characteristics of demand and supply into the model. Results indicated that potential access to healthcare significantly differs between neighborhoods for all spatial and aspatial dimensions of access. Therefore, the proposed method better suited the study of locally relevant natural neighborhood units. Finally, some authors have also considered different types of travel modes in the 2SFCA. Langford et al. (2012), for example, proposed an accessibility measure based on the 2SFCA to determine access to public transport opportunities. Mao and Nekorchuk (2013), on the other hand, suggested a multi-mode 2SFCA method and showed that their method provides more realistic accessibility estimations when accounting for heterogeneity in populations.

2.3.2 The commuter-based two-step floating catchment area method

Relying on the work discussed in the previous section, this paper presents an important extension of the 2SFCA method. It consists of the consideration of daily commuting behavior in both the first and second step of the FCA procedure in order to arrive at what will be called the commuter-based two-step floating catchment area (CB2SFCA) method. In this method, the demand is not simply equated to the number of inhabitants that are stationary within a zone but is made dependent on the commuting behavior of the inhabitants whose location is considered to vary within the study area. In order to differentiate accessibility based on commuting behavior, origin-destinations matrices (ODM) are used to determine travel times from the zonal centroids to other zonal centroids and from the zonal centroids to the facilities and vice versa. As is the case in the original 2SFCA analysis, the method is implemented in two steps. In step 1, a commuter-based PPR D_k is determined for each facility k:

$$D_k = \frac{C_k}{\sum_{i,j \in \{t_{i,k} \leq t_f \ \ and\ t_{i,k}+t_{k,j} \leq t_{i,j}+t_d\}} n_{i,j}} \tag{9}$$

where C_k is the capacity in facility k, $t_{i,j}$, t_{ik} and $t_{k,j}$ represent the calculated travel time from departure zone i to destination zone j, from departure zone i to facility k and from facility k to destination zone j respectively, t_f equals the travel time threshold to a facility, t_d equals the detour travel time threshold, and $n_{i,j}$ denotes the actual number of commuters between departure zone i and destination zone j. Conceptually, each facility's capacity is divided by the number of commuters that is able to reach that facility given a travel time threshold to the facility and a detour travel time threshold. The detour travel time corresponds with the extra time needed to add the facility location to the trip chain from home to work and vice versa. Therefore, two conditions are to be fulfilled for a certain $n_{i,j}$ in order to be included in the summation of the denominator of D_k. These conditions are:

$$t_{i,k} \leq t_f \tag{10}$$

$$t_{i,k} + t_{k,j} \leq t_{i,j} + t_d \tag{11}$$

Equation (10) indicates that the travel time of the initial commute from the home location to the facility cannot exceed the maximum travel time to a facility. Equation (11) specifies that the sum of the total travel time from the home location to a facility and the facility to the work location has to be equal to or less than the sum of the travel time from the home location to the work location and the maximum detour travel time. In step 2, an accessibility ratio A_i is determined for each census tract centroid i:

$$A_i = \sum_{j,k \in \{t_{i,k} \leq t_f \ \ and\ t_{i,k}+t_{k,j} \leq t_{i,j}+t_d\}} D_k \tag{12}$$

where D_k is the commuter-based PPR in facility k, $t_{i,j}$ represents the travel time from departure zone i to destination zone j, $t_{i,k}$ represents the travel time from departure zone i to facility k and $t_{k,j}$ represents the travel time from facility k to destination zone j, t_f equals the maximum travel time to a facility and t_d equals the maximum detour travel time. As for the calculation of D_k in step 1, the same conditions (10) and (11) have to be met simultaneously to include a certain D_k in the summation when calculating the accessibility ratio A_i. Consequently, the demand is modeled based on the travel behavior from the home to the work location, whereas the static calculation of the catchment area in the 2SFCA method is based solely on the home location.

2.3.3 Example of the CB2SFCA

In this example, simulated travel times between the centroids of zone *K*, *L* and *M* are linked to a certain amount of commuters between the centroids, resulting in six interzonal travel flows: *KL*, *LK*, *KM*, *MK*, *LM* and *ML*. For example, between zone *K* and *L*, the travel time t_{KL} equals 7 minutes, while a total of 50 commuting trips from zone *K* to *L* are made on a daily basis (Fig. 4).

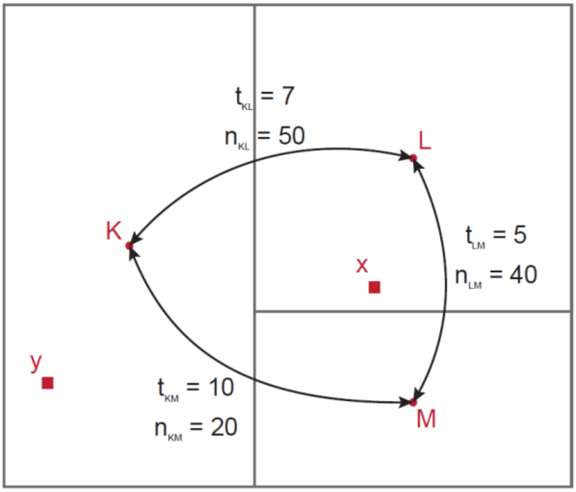

Fig. 4. Simulated travel times and amount of commuters between zone K, L and M

The capacity in each facility *x* and *y* is constant and equal to 20. For simplicity, the amount of commuters and the travel times between zones are considered to be identical in both directions ($n_{KL} = n_{LK}$ and $t_{KL} = t_{LK}$). In reality however, traffic situations (e.g. one-way streets) lead to different travel times to and from a specific zone. Also, intrazonal travel is not considered in this example. These complexities are dealt with in the detailed case study of the paper. The travel time threshold to a facility t_f as well as the detour travel time threshold t_d are predefined parameters to be determined by the analyst or policy maker in relation to the case study at hand. Although higher values for the parameters lead to more detailed accessibility ratios, they also result in more complex calculations. For feasibility of implementation, both parameters are set to 10 minutes in this example.

Table 1. Commuter-based PPRs calculated in step 1 of the CB2SFCA

Facility	C	Considered flows	Sum of all commuters	D
x	20	$n_{KL} + n_{LK} + n_{KM} + n_{MK} + n_{LM} + n_{ML}$	220	1/11
y	20	$n_{KM} + n_{MK}$	40	1/2

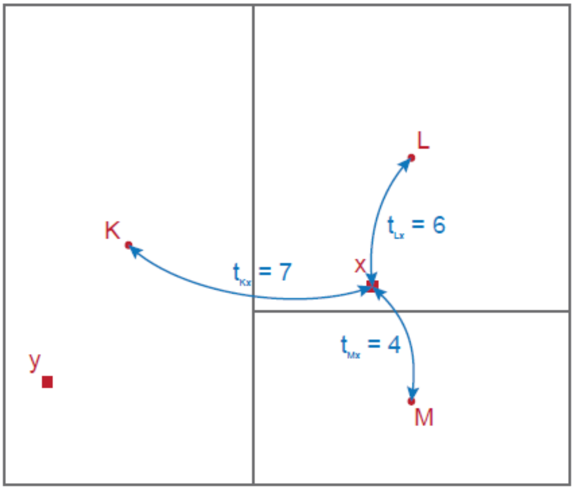

Fig. 5. Calculation of the commuter-based PPR in x

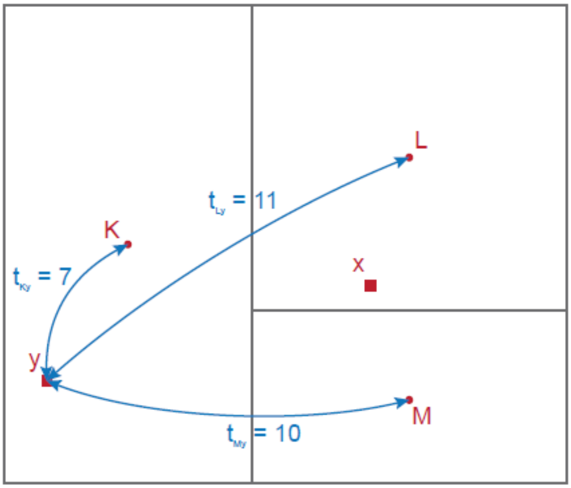

Fig. 6. Calculation of the commuter-based PPR in y

When applying the same conditions for the calculation of the commuter-based PPR in *y* (D_y), not all conditions are met for every interzonal flow. Condition (10) is met for t_{Ky} and t_{My}, but t_{Ly} surpasses the ten minutes travel time limitation from the home location to the facility. Therefore, n_{LK} and n_{LM} are disregarded. As for condition (11), $t_{Ky} + t_{yM} \leq t_{KM} + 10$ and $t_{My} + t_{yK} \leq t_{MK} + 10$ are fulfilled for the flow between zone *K* and zone *M*, but the condition is not met for the flow between zone *K* and *L* ($t_{Ky} + t_{yL} = 18$, which exceeds $t_{KL} + 10 = 17$) as well as between zone *L* and *M* ($t_{Ly} + t_{yM} = 21$, which exceeds $t_{LM} + 10 = 15$). As a result, only n_{KM} and n_{MK} are taken into account for determining the PPR. D_y equals the capacity in *y* ($C_y = 20$) divided by the sum of all relevant number of commuters ($n_{KM} + n_{MK} = 40$). The PPR for facility *y* thus equals 1/2 ($C_y/n_{TOT} = 20/40$) and indicates the facility's capacity in relation to the amount of commuters which are capable of reaching the facility within a 10-minute detour.

Table 2. Accessibility ratios calculated in step 2 of the CB2SFCA

Home location		**K**	
	Work location	Considered D	A
	L	Dx	1/11
	M	Dx + Dy	13/22
			15/22
Home location		**L**	
	Work location	Considered D	A
	K	Dx	1/11
	M	Dx	1/11
			4/22
Home location		**M**	
	Work location	Considered D	A
	K	Dx + Dy	13/22
	L	Dx	1/11
			15/22

For the second step of the CB2SFCA, the accessibility ratio for centroid K (A_K) is calculated as the sum of all accessibility ratios per interzonal flow between centroid K as home location and centroid L or M as work location (A_{KL} or A_{KM}, Fig. 7). The corresponding values for centroid K are listed in Table 2. For the accessibility ratio A_{KL}, condition (10) is met: t_{Kx} and t_{Ky} do not exceed ten minutes. Also condition (11) is fulfilled for the travel times from centroid K to centroid L via x: $t_{Kx} + t_{xL} \leq t_{KL} + 10$. However, for the travel times from centroid K to centroid L via y, this condition is not met ($t_{Ky} + t_{yL} = 18$, which surpasses $t_{KL} + 10 = 17$). Therefore, only the commuter-based PPR in x (D_x) is considered, resulting in an accessibility ratio A_{KL} of 1/11 (D_x). For the accessibility ratio A_{KM} both conditions are fully met. t_{Kx} and t_{Ky} do not exceed 10 minutes, thus fulfilling condition (10). Additionally, $t_{Kx} + t_{xM} \leq t_{KM} + 10$ and $t_{Ky} + t_{yM} \leq t_{KM} + 10$ for condition (11) are satisfied. Therefore, both the commuter-based PPR in x (D_x) and y (D_y) are taken into account, resulting in an accessibility ratio A_{KM} of 13/22 ($D_x + D_y = 1/11 + 1/2$). Summarizing both A_{KL} and A_{KM} results in the total accessibility ratio for centroid K, where A_K equals 15/22.

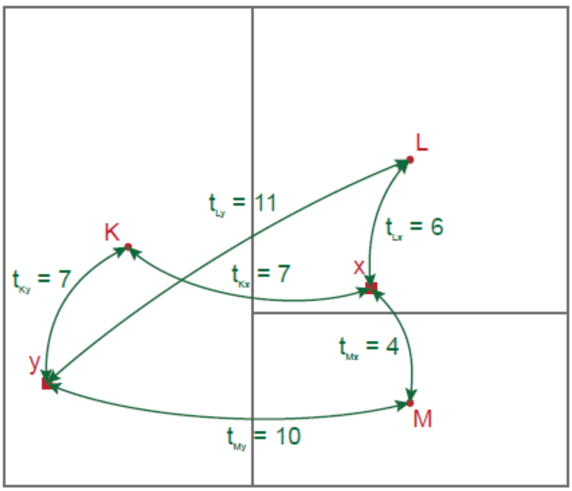

Fig. 7. Calculation of the accessibility ratio in zones K, L and M

Analogous to the calculation of A_K, the accessibility ratios for centroids L (A_L) and M (A_M) are calculated as the sum of all accessibility ratios per interzonal flow between centroid L and M as home location and centroid K or M (A_{LK} or A_{LM}) and centroid K or L (A_{LK} or A_{LM}) as work location, respectively (Fig. 3). This results in an accessibility ratio A_L equal to 4/22 and A_M equal to 15/22 (Table 2).

2.4 Case study

The study area is the province East Flanders in Belgium with a population of approximately 1.4 million inhabitants on an area of 2,982 km². The province is divided into 65 municipalities and 2,215 census tracts (Fig. 8). The addresses of all active daycare centers for the Flemish speaking community for children aged two years and younger were geocoded. There are 9,335 daycare centers in Flanders of which 2,312 are located in the province of East Flanders. The data was provided by the Flemish agency Child and Family.

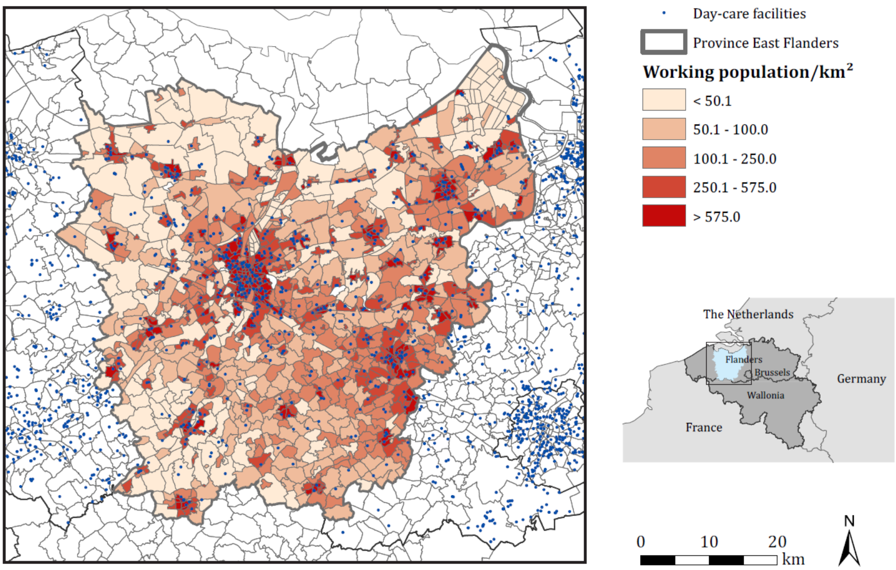

Fig. 8. Study area specifying the location of the daycare facilities in Flanders and the density of the working population per traffic analysis zone in the province East Flanders

In order to calculate shortest paths between daycare centers and census tract centroids, a transportation network shapefile (TomTom MultiNet) was applied, containing a comprehensive topological representation of the Belgian road network. In order to consider the distance travelled per trip and the amount of trips travelled from home to work, the origin-destination cost matrices (ODCM) of the Flanders Multimodal Model (MMM) were used. The MMM is a macro traffic model commissioned by the Flemish government and developed since 1998. The dataset was calibrated based on data from the nation-wide census, traffic counts and the regional activity-travel diary Travel Behaviour Survey for Flanders ('Onderzoek Verplaatsingsgedrag' or OVG). In this model, traffic between different traffic analysis zones (TAZ) is simulated for an average weekday between 4 am and 11 am in the morning traffic, thus representing the daily travelled distances to and from each neighborhood and the amount of travels per activity group (work, education, shopping, leisure and remainder). These TAZs are mostly in line with the census tract borders (Verhetsel et al., 2007). The model consists of five sub models, one for each province in Flanders. For this study, the data for the province of East Flanders were used. The province contains 1,134 TAZs. As population dataset for this research, the working population per TAZ was applied. The sum of inhabitants travelling from the home location in each TAZ to the work location in the same or another TAZ per square kilometer are represented in Fig. 8. All applied Esri ArcGIS functionalities and general calculations were scripted in Python in order to automatize the spatial procedures.

In consultation with the agency Child and Family a catchment area of 10 minutes was calculated for the 2SFCA to indicate daycare centers accessible from the home location. Correspondingly, a maximum detour cost of 10 minutes in addition to the shortest path between two zones or between a zone and a daycare center was applied to determine accessible daycare centers for the CB2SFCA method. Furthermore, daycare centers located at more than a 10-minute travel time from the home location were not regarded.

2.5 Results

2.5.1 Statistical analysis

For the analysis, calculated accessibility ratios are standardized based on their maximum value. The means of the 2SFCA and CB2SFCA methods are compared in an independent samples T-test (Table 3). In combination with the descriptive statistics for both methods found in Table 4, the test indicates that the average of the CB2SFCA method differs significantly ($p < 0.001$, $F = 13.800$) from the average of the 2SFCA method (2SFCA method 0.564 ± 0.166 and CB2SFCA method 0.666 ± 0.152).

The Pearson product moment correlation coefficient shows that the CB2SFCA method is positively correlated with the 2SFCA method. In addition, regression analysis shows that 55% (adjusted $R^2 = 0.549$, $p < 0.001$) of the variance in the 2SFCA method is predicted by the CB2SFCA method. Therefore, both methods exhibit a strong mutual correlation.

Table 3. Independent samples test for equality of variances (Levene's Test) and means (t-test)

	Levene's Test	t-test	
	F	t	df
Equal variances assumed	13.800*	-15.136*	2,266
Equal variances not assumed		-15.136*	2,249

* Coefficients are significant at the 0.05 level.

Table 4. Descriptive statistics of the different accessibility analysis methods

Method	N	Mean	Std. Deviation	Std. Error Mean
2SFCA	1,134	0.565	0.166	0.005
CB2SFCA	1,134	0.666	0.153	0.005

Furthermore, the 2SFCA tends to underestimate accessibility compared to the CB2SFCA method. In order to facilitate this comparison, the scores for both methods are normalized to unity. As shown in Fig. 9, there are more points below the 1:1 line, thus indicating overall higher accessibility values when applying the CB2SFCA. This is in accordance with greater ease of access when taking into regard the commute from home to work instead of solely calculating accessibility from the home location.

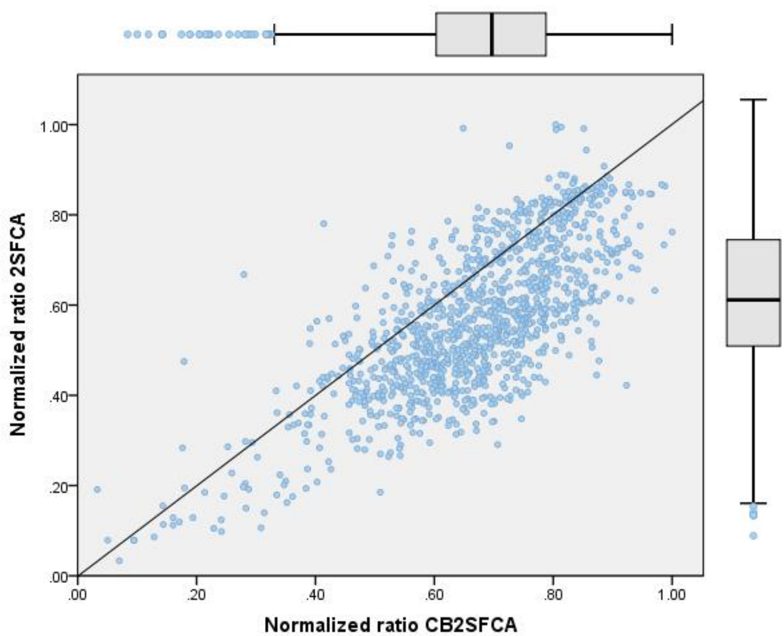

Fig. 9. Scatter plot comparing the CB2SFCA method to the 2SFCA method

2.5.2 Geographical analysis

The statistical analysis shows that both methods significantly differ from each other and that the 2SFCA tends to underestimate the accessibility values in comparison to the CB2SFCA. However, it still remains unknown where these differences in accessibility are situated geographically. Therefore, the values of accessibility are spatially compared by implementing the quintile method. Because the CB2SFCA incorporates a more complex travel behavior in accessibility analysis, a more detailed spatial distribution is measured.

Fig. 10 shows that the spatial distribution of accessibility measured by the CB2SFCA method is more heterogeneous compared to the 2SFCA method. This is underlined by a higher Moran's I z-value for the 2SFCA (z-value = 104.89) in comparison to the CB2SFCA (z-value = 69.16), indicating a stronger clustering of the accessibility values and, as such, a less heterogeneous distribution. For the 2SCFA, higher accessibilities are noted in and nearby larger cities. The CB2SFCA also highlights large cities but is able to identify smaller accessible urban centers in the non-urban zones. Rural areas where a large amount of people depart to work are also characterized by a higher accessibility to daycare centers, although they do not have a large amount of facilities in their direct vicinity. As such, the CB2SFCA method additionally indicates higher accessibility for suburban areas with a large number of commuters.

Due to the availability of inter-zonal travel between the TAZs in East Flanders, only commuter behavior within the study area was considered. Both methods are influenced by edge effects as regions adjacent to the zones of the study area are not incorporated in the accessibility analysis. Consequently, the calculated ratios are underestimated near the boundaries of the study area. The dataset for the daycare centers was applied at the level of Flanders and was only available for the study area and the areas located west and east of it. Therefore, the underestimations are articulated most strongly in the northern and southern part of the study area. In order to more clearly visualize the results obtained by both methods, the differences between both methods are mapped in a separate figure (Fig. 11). To this end, the accessibility values have been standardized in the range between 0 and 1. A positive outcome indicates higher accessibility values when applying the CB2SFCA method in comparison to the 2SFCA and vice versa. Geographically, relative accessibility is lower or equal in urban agglomerations (e.g., Ghent, Sint-Niklaas, Lokeren or Oudenaarde), but higher in suburban and rural areas.

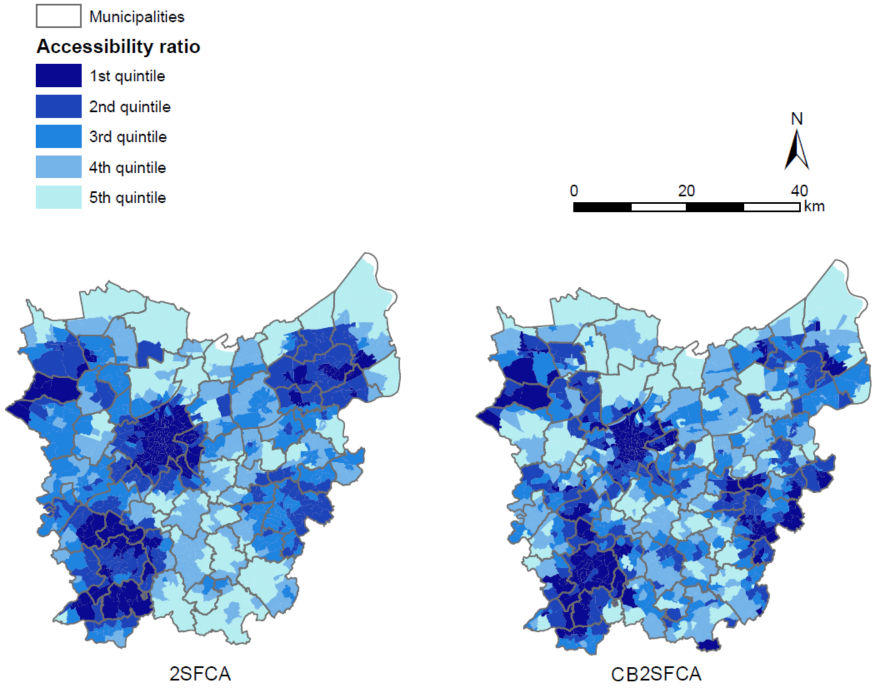

Fig. 10. Accessibility to daycare centers in East Flanders by implementing the 2SFCA and CB2SFCA methods

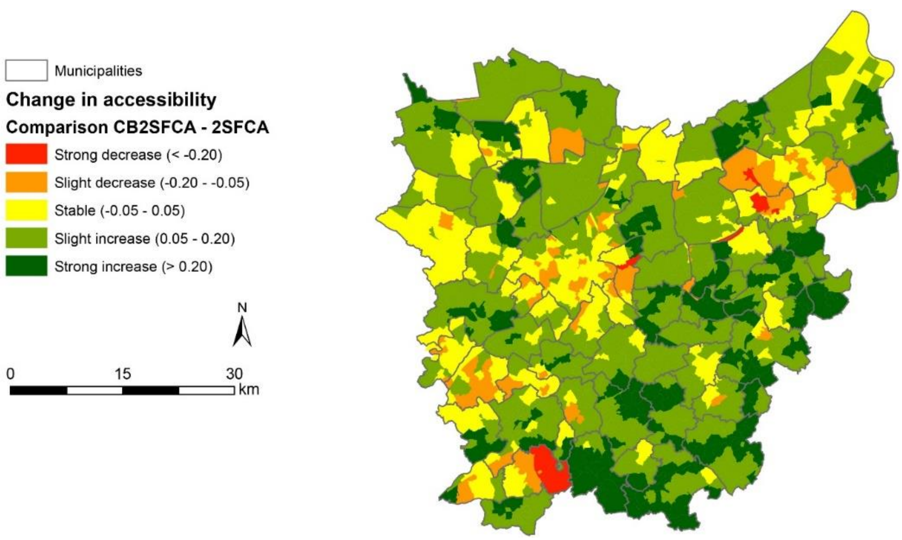

Fig. 11. Change in accessibility when comparing the CB2SFCA to the 2SFCA method

A relative decrease in accessibility is explained by the larger commuter flows (and, therefore, stronger impact of the competition factor) to areas with less opportunities. A relative increase (in comparison to the 2SFCA where the catchment area is situated around the home location with less opportunities) indicates a smaller competition factor due to lower commuter flows in combination with primarily commutes to urban areas where the number of opportunities is higher. Especially the southwest of East Flanders is characterized by a high relative increase in accessibility to daycare centers when the CB2SFCA is employed, because of the high amount of commuters to the major business center located in Brussels to the west. These results show that the introduction of trip chaining behavior into the accessibility analysis has a significant impact on the resulting accessibility pattern. In addition, accounting for commuter patterns primarily positively influence the measured accessibility levels in the Flemish, urbanized environment.

2.6 Summary and discussion

This paper has proposed a new method for determining spatial accessibility to daycare centers that accounts for daily mobility patterns. The projected method adds behavioral realism to the current metrics that are based on static, centroid-based night-time representations of the population. More specifically, this paper has introduced trip chaining behavior from home to work within certain detour cost limits into the FCA method. As an illustration of the method, a case study of accessibility of daycare centers was elaborated. Taking more complex travel behavior into account has resulted in significantly different spatial patterns of accessibility. In contrast to the traditional static approach, the CB2SFCA method is capable of identifying areas where the amount of commuters from home to work is not in balance with the available capacity of daycare centers in the vicinity of the trip chains. This could lead to interesting policy recommendations to shift the focus from planning for locations (or rigid planning) to planning for movement patterns (or dynamic planning).

Although the proposed commuting-based accessibility metric is not suitable for activities usually not combined in a trip chain (e.g. hospitalization), there are various types of services in the domain of public health that may benefit from the proposed metric. Particular illustrations are healthcare services that require regular visits often combined on a trip chain along to way to or from work. For example, hemodialysis (kidney dialysis) is a well-known therapy that is done thrice a week in a hospital or at a specialist and PUVA (Psoralen long-wave Ultraviolet radiation type A) phototherapy is a frequently applied treatment for dermatosis, which is performed two or three times a week at a dermatologist. Likewise, recurrent need for paramedical services, such as physical or speech therapists, can often be combined with other activities. Furthermore, being able to access these facilities from the commute from work to home makes better use of the opening hours of the services. However, while the presented approach is a valuable first step towards more individualized metrics of health care accessibility, some refinements are required in future work.

A first refinement is to empirically estimate catchment area size and detour cost. Although data on activity travel behavior was available for the study area, no specific travel times for dropping off or picking up children at daycare centers existed. The applied categories are too broad in most travel diary surveys, which makes it impossible to determine the maximum detour cost commuters are willing to spent in order to reach a daycare center. Therefore, catchment area size and detour costs were determined in this case study in consultation with experts from the Flemish agency Child and Family and are specific to the context at hand. However, future research should undertake dedicated estimation procedures using bespoke data sets in order to introduce distance decay into the CB2SFCA. Analogous to the enhanced two-step floating catchment area (E2SFCA) method developed by Luo and Qi (2009), accessibility should increase with decreasing detour travel time. In contrast to the E2SFCA, the decay could be linearly calculated instead of using arbitrary weights for discrete catchments, because all travel times between zones and facilities are known. Increasing or decreasing the values will impact the CB2SFCA stronger than the 2SFCA. For the latter, the clusters of high accessibility (in the urban areas) will increase or decrease, whereas this is harder to predict for the former. Given the same distribution of flows, one would expect to have similar results for lower or higher catchment areas, yet the nuances in comparison to the 2SFCA will decrease or increase, respectively.

Second, the commuter flows accounted for in the case study analysis account for all transport modes (private motorized vehicle, public transport, bicycle), as the applied MMM model data does not discern between different modes. This does not match the travel time analysis, which solely examines the travel times by private motorized vehicles.

A significant number of parents, however, uses the bicycle to combine dropping off and picking up their children at the daycare and commuting (in Flanders, for example, 15.40% commute by bicycle), especially in urban settings. Although this limitation does not directly impact the proposed CB2SFCA methodology, it poses a restriction to the possible policy recommendations derived from the case study example. In addition, the applied car-based network dataset does not account for congestion times, which might strongly impact commuter-based accessibility during the morning and evening peak.

Third, the demand for services needs to be differentiated in future work. In the current method, the entire working population is considered to be part of the demand for daycare. However, not every person commuting to work has children and not all parents make use of official daycare facilities. This leads to an overestimation of the demand of daycare. Integrating non-spatial factors such as demographic and socioeconomic variables that impact health care access is an important challenge (Wang, 2012). The current method allows accessibility to be examined for specific population groups such as those on low income or without a privately owned vehicle. Finally, following the 3SFCA method suggested by Wan et al. (2012), a spatial impedance-based competition scheme could be incorporated into the CB2SFCA method to account for competition between closely located daycare centers. We hope to contribute to these and other areas of study in the near future.

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Chapter 3: Public transport gaps in Flanders

A fair transport system should focus on the needs of the person using the system instead of merely the provision of mobility itself. The current length of traffic jams shows the success and, therefore, the already sufficient quality of the road network. In practice, this calls for a significant shift from (policy) investments in asphalt to investing in high-quality regional public transport.

Karel Martens, 2016

This chapter is adopted from the following journal article: Fransen, K., Neutens, T., Farber, S., De Maeyer, P., Deruyter, G., Witlox, F. (2015). Identifying public transport gaps using time-dependent accessibility levels, Journal of Transport Geography, 48, pp. 176-187,

Abstract

One of the concerns that has aroused much scholarly attention in transport geography lately is the extent to which public transport provision enables the less privileged population segments, especially those without privately owned motorized vehicles, to participate in activities that are deemed normal within the society they live in. This study contributes to this line of inquiry by proposing a methodology for identifying public transit gaps, a mismatch between the socially driven demand for transit and the supply provided by transit agencies. The methodology draws on the latest accomplishments in the field of modeling time-continuous, schedule-based public transport accessibility. Accessibility levels to key destinations are calculated at regular time intervals, and synoptic metrics of these levels over various peak and off-peak time windows are computed for weekdays and weekends. As a result, a temporally reliable picture of accessibility by public transport is constructed. The obtained index of public transport provision is compared to a public transport needs index based on the spatial distribution of various socio-demographics, in order to highlight spatial mismatches between these two indices. The study area consists of Flanders, which is the northern, Dutch-speaking region of Belgium. The results indicate that mainly suburban areas are characterized by high public transport gaps. Due to the time-variability of public transport frequencies, these gaps differ over time.

Keywords: transport gap, transport disadvantage, social exclusion, public transport, GIS, Flanders

3.1 Introduction

The past two decades have witnessed a large and growing academic and policy interest in the social implications of transport planning alongside the traditionally well-studied economic and environmental outcomes (Lucas, 2012). Understanding the ways in which inadequate or lack of mobility can contribute to social disadvantage and isolation has been brought to the forefront of the transport policy agenda. Currently, there is a wide recognition that transport policies may generate spatially and temporally uneven accessibility effects that unduly favor certain population groups above others (Grengs, 2015).

One of the concerns that has recently aroused much scholarly attention is the extent to which public transport provision enables the less privileged population segments, especially those without privately owned motorized vehicles, to participate in activities that are deemed normal within the society they live. Various studies conducted under the umbrella domain of transport-related social exclusion have used geographical information systems (GIS) to unravel the connections between social disadvantage, public transport needs and public transport provision. However, much of the empirical work to date has explored these connections by examining social disparities in access *to* the public transit system rather than *by* the transit system. For example, in their assessment of the impact of bus network changes on different social groups in Northern Ireland, Wu and Hine (2003) suggested the use of public transport accessibility levels (PTAL) which essentially express accessibility as the sum of walking time to the closest bus stop plus average waiting time at that stop. Likewise, Currie (2010) applied a combined indicator of access to public transit stops (e.g. spatial coverage of walk catchments around public transport stops/stations) and their relative service (e.g. the number of bus/tram/train vehicle arrivals per week). While such indicators are insightful in identifying socio-spatial differences in access to the public transport system, they do not provide insights into whether the system brings people to desired activity locations within an acceptable travel time at the desired time of day. Furthermore, these indicators ignore that inadequate proximity to public transport provision can be compensated by local availability of amenities. Other recent studies that link transit access to social disadvantage like Delmelle and Casas (2012) assumed that public transport vehicles ride at a constant travel velocity in order to be able to construct a routable walk-transit network layer. Their multimodal approach accounted for ingress and egress time, but ignored wait and transfer times leading to an underestimation of the overall journey travel time. Other cognate studies have calculated end-to-end travel times by public transit using bespoke database software tools such as Amelia (Mackett et al., 2008) and Accession (Preston & Raje, 2007). While these tools have proven useful in aiding transport planners in the UK to compare the impact of policy actions, they are unavailable to the wider academic public. Furthermore, they offer rather limited flexibility to analysts in order for them to develop their own procedures on top of the functionalities embedded in the software. The accessibility metrics produced by these tools are therefore static in the sense that they describe what is accessible by public transit from a particular origin at a single point in time but do not consider the temporal variability in accessibility levels. Such temporal variability occurs as a consequence of fluctuations in operating frequencies across the diurnal cycle and between weekdays and weekends.

This study contributes to the strand of literature outlined above. It puts forward a methodology for identifying public transit gaps by drawing on the latest accomplishments in the field of modeling time-continuous, schedule-based public transport (Steven Farber et al., 2014; Lei & Church, 2010; Owen & Levinson, 2014). It measures accessibility levels to key destinations for socio-spatial population groups at regular time intervals and computes synoptic metrics of these levels over various peak and off-peak time windows on weekdays and weekends. The obtained metrics of transport provision are then compared across social cross-sections of the population and compared to a public transport needs index to highlight spatial mismatches between provision and need. The study area consists of Flanders, which is the northern, Dutch-speaking region of Belgium. This region constitutes an interesting and challenging setting for studying public transport gaps since it is characterized by a highly dense public transport infrastructure with a variety of public transport alternatives run by different operators. Furthermore, since 2001 the region has adopted a clear-cut stance towards combatting transport poverty. Flanders is one of the only regions in the world where the right to basic provision to public transport, formulated as having spatial access to a minimum level of public transport service irrespective of the location of residence, is granted by law (decree '*Personenvervoer*'). In the UK, local transport authorities are required to publish accessibility assessment reports as part of their Local Transport Plans (Atkins, 2012). Within this context, budgetary pressure has prompted the public transport company *De Lijn* to search for new cost-effective alternatives (e.g. mobility budgets and neighborhood buses) to continue guaranteeing sufficient service in all parts of the region. The results reported in this study have served to set the stage and inform *De Lijn* about the deficits in coverage of their system in Flanders.

The paper proceeds with a brief review on the measurement of transport gaps and discusses how accessibility by public transport was modeled in prior work. Subsequently, it contextualizes the research within the study area and describes the data and methodology. The results are presented in Section 4. The paper concludes with the major findings and outlines avenues for further research.

3.2 Literature review

3.2.1 Measuring public transport gaps

Policy concerns related to social disparities in mobility and access to essential goods and services have emerged and grown in tandem with a wider policy interest in the causes and effects of social exclusion. Policy interest in social exclusion originated in the United Kingdom in the late 1990s as part of a broader social welfare reform under the New Labour government. A Social Exclusion Unit (SEU) set up in 1997 has sparked off a series of policy documents including a widely applauded report that focuses on the interactions between social disadvantages and transport disadvantages and how these interactions can culminate into situations of transport poverty and exclusion. Since the publication of the report, researchers from around the world have built up empirical evidence of social exclusion as a result of transport problems. Evidence has mounted in Europe (Priya & Uteng, 2009; Schönfelder & Axhausen, 2003), North America (S. Farber et al., 2011; McCray & Brais, 2007; Paez et al., 2010), Latin America (Delmelle & Casas, 2012; Jaramillo et al., 2012), Australia (Delbosc & Currie, 2011; Stanley & Vella-Brodrick, 2009), and Africa (Lucas, 2011; Porter et al., 2012).

Within this emerging body of international literature much attention has been devoted to the quality of public transport and more specifically to designating individuals and areas that suffer from public transport deficiencies. However, quantifying to what extent a person suffers from public transport deficiencies is difficult because transport poverty manifests itself at the individual and household level, whilst appropriate data sets are generally available at a zonal level (Hine & Grieco, 2003; Karner & Niemeier, 2013). Furthermore, it is difficult to determine when a person is to be considered transport poor.

By definition (Lucas, 2012, p. 106), this has to do with the inability to access a 'normal' range of activity locations, but the exact meaning of such a 'normal range' remains absent, apart from it being the range of activities that is available to the majority of people in society (Levitas et al., 2007). The necessity of being able to reach certain destinations evidently differs for each individual and in different societies. Having access to education, for example, is more important to students than to the elderly, whereas the opposite may be true for health care. Hence, it is up to the analyst to judiciously decide which destinations matter in the case study at hand. Another issue is the definition of the concepts 'access' and 'inability to access' and whether these have to be conceptualized in normative or relative terms. 'Normative' refers to an absolute threshold that represents policy makers' expectations about the minimum required level of accessibility, while 'relative' pertains to a particular benchmark (e.g., a population average) that expresses the accessibility levels of other individuals in the same society (Paez et al., 2012).

A common strategy to quantify socio-spatial deficits in public transport provision is to construct and compare two indices: one that expresses public transport needs and another that represents public transport provision. The former is composed of indicators that describe area-based populations who are most in need of public transport on the basis of such variables as car ownership, income, employment and age. The latter is an index representing how well an area is serviced by the public transport system. The difference between both indices is then termed the 'transport gap' which acts as a proxy for an area's vulnerability to developing transport poverty. Of particular interest are those areas with low provision and high need as well as those with low need and high provision as these cases represent situations of under-service and over-service, respectively. Exemplary to this approach is the work by Currie (2010) who found significant spatial patterns of 'high need – low provision' in Metropolitan Melbourne (Australia). Those patterns were also detected in Santiago de Cali (Columbia) by Jaramillo and colleagues (2012) using a similar methodology. The constructed disadvantage-impedance index by Duvarci et al. (2015) aims to counteract transport disadvantages by simulating the effects of potentially efficient policy alternatives in Arao, Japan. Aggregation errors notwithstanding, these studies help to understand the relative spatial scale of public transport shortfalls which can help inform policy makers regarding the spatial prioritization of transport policy actions. For this reason, a similar research strategy is adopted in this study.

3.2.2 Modelling public transport accessibility

Modelling public transport accessibility has a long history with a trend towards increasingly sophisticated measurements. At least four types of indicators of public transport accessibility can be identified. The first type measures the physical accessibility to the public transport system in terms of the proximity to transit stops in time or distance (Lei & Church, 2010). A commonly applied indicator is the walking distance from the centroid of an administrative unit to a public transport stop. An archetype of such indicator can be found in a study by Gutierrez and Garcia-Palomares (2008), who determined public transport coverage of interurban buses in Madrid. While simple and easily computed, proximity indicators offer only an incomplete picture of public transport accessibility as they disregard the service offered at each of the stops, the desired destinations within reach and the travel time to these destinations (Mavoa et al., 2012).

A second type of indicator additionally accounts for the importance of the public transit stops within the overall transit network. To that end, service frequencies at transit stops are often summarized per stop. To estimate transit equity in the Washington-Baltimore region (US), Welch and Mishra (2013) incorporated public transport frequency as an attribute that varies distinctly between peak and off-peak commuting times in a multi-modal transportation network.

Third, in addition to physical accessibility to the transit system and the level of service offered by the system, some indicators account for the time or cost associated with the journey to the considered destinations. This requires the construction of a routable transportation network as well as the implementation of bespoke GIS procedures. Benenson et al. (2011), for example, developed the Urban.Access ArcGIS extension tool, which combines congestion-based real-world estimates of travel speed with bus schedules. This tool enabled to estimate car-based and transit-based accessibility to employment and other land uses and compare accessibility levels by transport mode in Tel-Aviv, Israel in an investigation of modal equity. Lei and Church (2010), for their part, proposed a GIS data structure to estimate the bus service time as the temporal dimension in a transit accessibility analysis in Santa Barbara, California. They also account for the time of day of the analysis by designating a specific departure or arrival time at one origin or destination respectively. The studies mentioned above are able to delineate which locations are reachable within a certain time budget, but they do not consider the number and type of opportunities within reach. Hence, certain studies additionally described access to specific location types. The simplest indicator is the number of a particular type of opportunity (e.g. jobs, schools, healthcare facilities etc.) available within a predetermined transit travel time. To assess the inter-modal equity by regional transportation, Golub and Martens (2014) applied a cumulative-opportunity approach that sums the number of essential destinations within predefined travel-time buffers by transit and automobile.

However, travel times by public transit fluctuate over time, and hence accessibility provided by the public transportation network is strongly influenced by the departure time (Lei & Church, 2010). To this end, a fourth and most sophisticated type of indicators has been developed to account for the temporal variability in public transit accessibility. Such indicators adopt a detailed door-to-door approach and consider the temporal (mis)matches between individuals' time budget in relation to transit timetables (e.g. Salonen and Toivonen, 2013). An important technical improvement in this respect includes General Transit Feed Specification files (GTFS) which allow construction of a multimodal public transport network dataset. GTFS is increasingly gaining attention from transport geographers. Hadas (2013) used GTFS to develop a GIS-based model enabling decision makers to (geo-)statistically analyze the connectivity within public transport networks. The model performed travel time analysis by incorporating published timetables based on average travel speeds of public transport vehicles. Other recent studies have applied GTFS data to construct a fully routable multimodal transportation network that enables estimating transit travel times at different times of the day (Steven Farber et al., 2014; Ma & Jan-Knaap, 2014; Owen & Levinson, 2014).

Simultaneously with the emerging policy interest in the causes as well as the effects of social exclusion, the literature outlined above clearly exhibits an evolution from basic metrics focusing on physical accessibility to more refined analysis methods. The paper builds on the most sophisticated approach outlined above in order to contribute to the increasing complexity of public transport accessibility analysis. Therefore, a time-continuous and schedule-based methodology was applied to identify transport gaps. As a result, a temporally reliable picture of accessibility by public transport is constructed, as is explained in Section 4.

3.3 Study area and data

3.3.1 Study area

The study area consists of Flanders, a densely populated region in the northern, Dutch-speaking part of Belgium, Europe. The region has a population of approximately 6.4 million inhabitants in an area of 13,597 km² and is divided in 308 municipalities, with strong concentrations in the cities of the larger agglomerations. Because of its central location and being a significant destination for Flemish travelers, destinations within Brussels and Wallonia (the southern, French-speaking part of Belgium) have also been considered in the analysis despite not being a part of Flanders. Both Flanders and Brussels have a higher population density in comparison to Wallonia located to the south (Fig. 12).

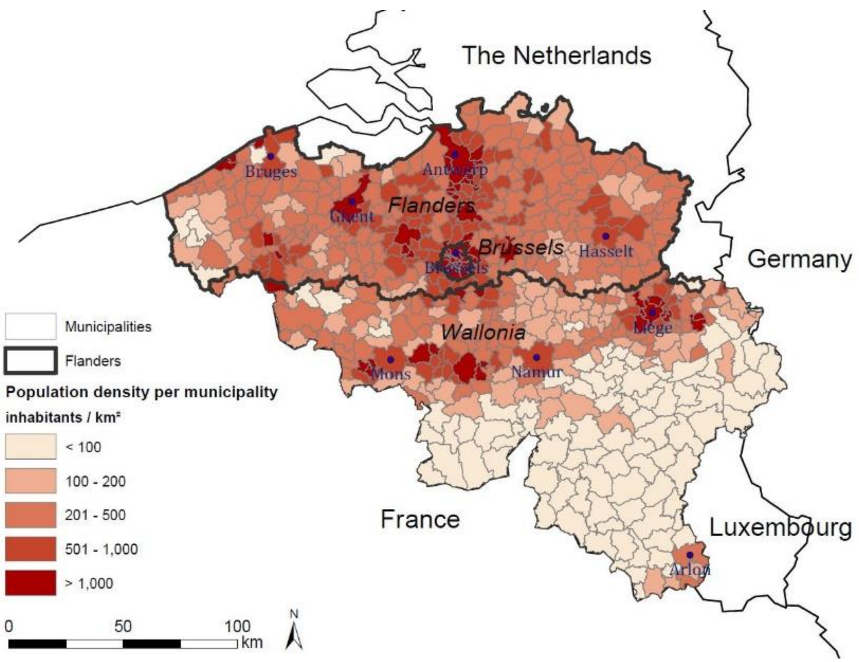

Fig. 12. Study area. specifying Belgium and its neighboring countries, the location of Flanders, Brussels and Wallonia, and the population density per municipality

3.3.2 Data

Three sources of data were used to measure public transport gaps in Flanders. First, the population size segmented by socio-demographic variables of the year 2013 was applied. These variable are either available per traffic analysis zone (TAZ) or at the municipality level. The categories of exclusion in transport are diverse, ranging from physical and spatial to socio-economic factors. Based on previous studies (Currie, 2010; Jaramillo et al., 2012; Kamruzzaman & Hine, 2011) and in consultation with experts from De Lijn, the most relevant information about the relative size of those socio-demographic groups that tend to depend largely on public transportation was chosen. These groups are depicted in Fig. 13 and include:

- percentage of the population aged 65 years and older (Fig. 13a);
- percentage of the population aged 6 to 11 years (Fig. 13b);
- percentage of households without privately owned motorized vehicle (Fig. 13c);
- percentage of the active population that is unemployed (Fig. 13d).

In addition, Fig. 13e depicts the percentage of the population receiving subsistence per municipality and acts as an indicator for an inhabitant's socio-economic situation. This information was made available by the Provincial Public Service Social Integration (*Provinciale Overheidsdienst Maatschappelijke Integratie*) and was aggregated on the municipality level due to unavailability per TAZ. According to Fig. 13, the age-related variables (percentage of the population aged 65 years and older and 6 to 11 years) and the variable related to car-ownership exhibit spatially random distributions, while the variables related to unemployment and subsistence are mainly characterized by a clustered pattern. This clustered distribution facilitates transit agencies to close public transport gaps, as localized service improvements can benefit a large amount of inhabitants. However, failing to provide sufficient service in clusters leads to a higher possibility of underserving large numbers of inhabitants at risk.

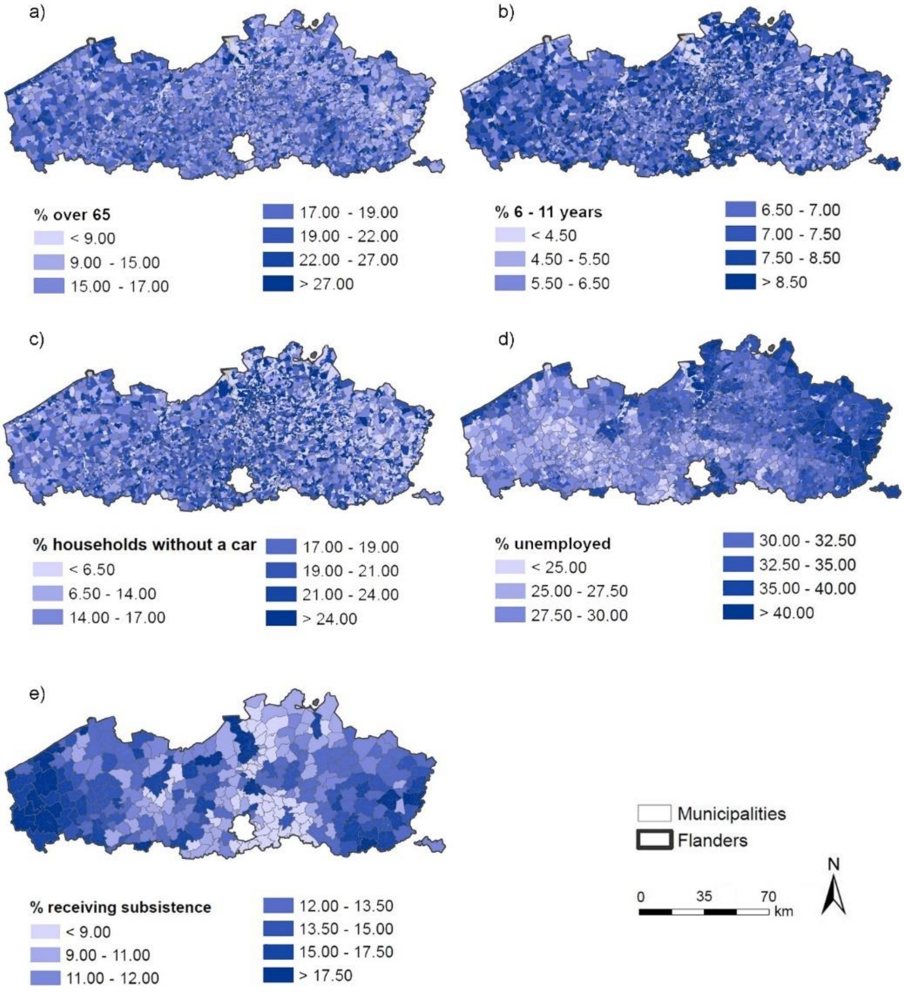

Fig. 13. Population aged 65 years and older (a), children aged between 6 and 12 (b), households without a car (c) and unemployed population (d) per PTAZ and population receiving subsistence allocation (e) per municipality in Flanders, quantile classification

A second group of data includes facility locations. Various types of indicators were geocoded at the address level and, when appropriate, opportunity constraints were aggregated at the TAZ level. These opportunities refer to the number of jobs and the student capacity available at each location. These, in combination with the data required to estimate travel times, were used to model the provision of facilities. The maps in Fig. 14 depict their spatial distribution. The study area is well covered with stronger concentration in the city centers. The addresses of the following active facilities in Belgium were implemented:

- 34,494 physicians, MDs, and other medical practitioners (Fig. 14a);
- 198 hospitals (Fig. 14a);
- 603 administrative centers (Fig. 14b);
- 2,064 supermarkets (Fig. 14c);
- 9,335 day-care centers (Fig. 14d).

The data was compiled from various sources. The dataset containing the locations of all medical practitioners in Belgium was provided by the National Institute for Disease and Invalidity Insurance (RIZIV), while those consisting of the hospitals, the administrative centers and the supermarkets were derived from the TomTom MultiNet. Furthermore, the addresses of all active day-care centers for the Flemish speaking community for children aged two years and younger were geocoded. The day-care center data was made available by the Flemish agency for Child and Family. The number of jobs (Fig. 14e) and the capacity in education (Fig. 14f) was provided by the public transport company *De Lijn*. Brussels was included in the job dataset due to the strong concentration of jobs in this area. Because both day-care centers and education are regionalized competences, this data was only incorporated for the Dutch-speaking region of Flanders. The variables were selected due to their availability on the address level and represent a cross section of primary needs that are considered crucial to improve an inhabitant's quality of life (health care, services, sustenance, education and employment). Therefore, the applied facility types have a universal and essential character and arguably make up a 'normal' range of opportunities that should be adequately accessible for all citizens in a society. Spatial autocorrelation indicates that all variables have a significantly clustered pattern (z-score > 1.96, p-value < 0.05). This clustering is strongly related to the location of the major city centers. When available, data about facilities located in Wallonia and/or Brussels are included in the analysis to alleviate edge effects. This means that individuals are assumed to be prepared to visit these facilities outside Flanders. However, a language barrier exists, and it is unknown to what extent this barrier affects the propensity to participate in cross-border activities.

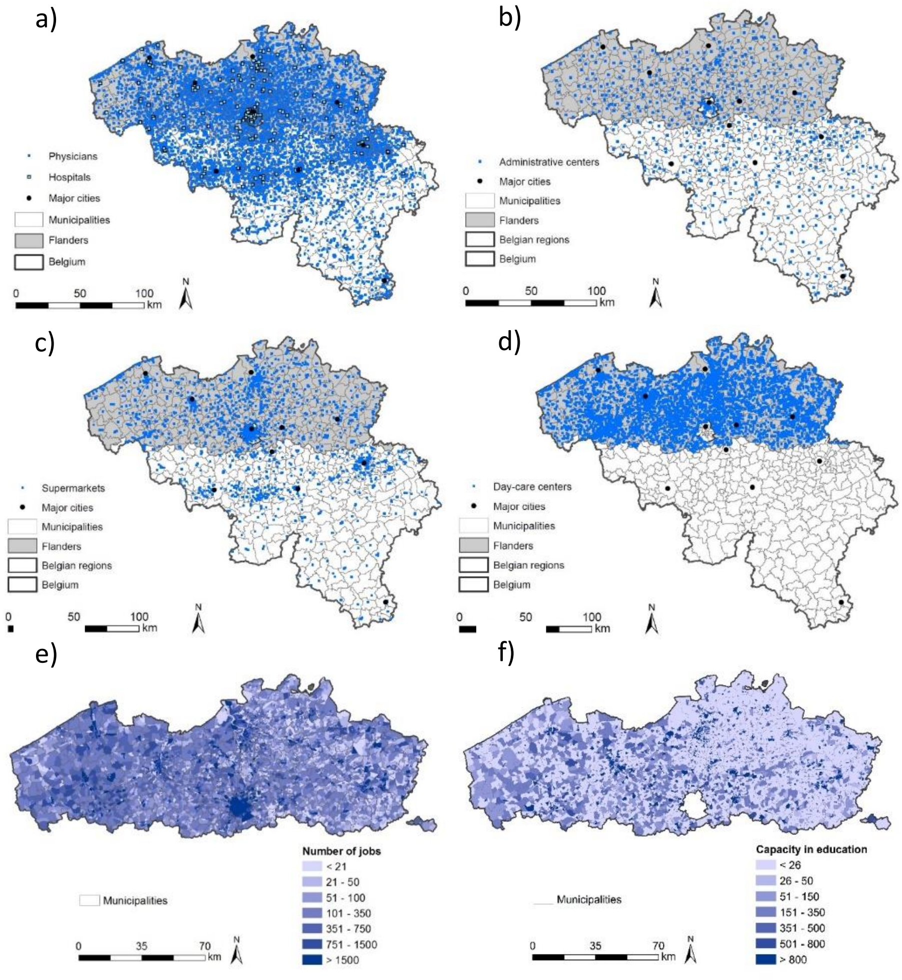

Fig. 14. Spatial distribution of healthcare facilities (a), administrative centers (b), supermarkets (c) and day-care centers (d) in Belgium and number of jobs (e) and capacity in education (f) in Flanders per TAZ

The third group of data comprises the transport network data. Analogous to Steven Farber et al. (2014), a routable network was created using the *Add GTFS to a Network Dataset* tools developed by Esri's Network Analyst Team. This tool enables integrating GTFS datasets for bus, tram, metro and train as well as street network data into a single multimodal network that accounts for the following components of a public transport trip: the walking time from the origin to the public transport stop through the pedestrian network (ingress), the waiting time at the public transport stop (including the time to enter or exit the vehicle), the actual travel time through the transit network (including transfers) using timetable information and the walking time from the public transport stop to the destination through the pedestrian network (egress). Incorporating the network into a Python script made it possible to iterate different functionalities (e.g. calculation of origin-destinations matrices and service area analyses) over various times of the day. Pedestrian travel for pre- and post-transit was estimated using the TomTom MultiNet version 2013.03, which contains a comprehensive topological representation of the Belgian road network. A walking speed of 4 km/h was assumed, which corresponds to an adult's average walking speed (Ritsema van Eck et al., 2005). This value is a modifiable network variable that could be used to represent travel speeds for different aged people or users of various ingress and egress modes (e.g. bicycles or motor vehicles). A built-in restriction excluded major motorways, highways and highway ramps from the network, since these are not accessible to pedestrians. The transit network dataset was constructed from the transit stops, routes and schedules specified in the GTFS datasets provided by various public transport companies: *Nationale Maatschappij der Belgische Spoorwegen* (NMBS) for transit by train in Belgium, *De Lijn* for transit by bus and tram in Flanders, *Transport en Commune* (TEC) for transit by bus and tram in Wallonia, and *Maatschappij voor het Intercommunaal Vervoer in Brussel* (MIVB) for bus, tram and metro in Brussels. Defining the connectivity of intersections of the transit and pedestrian network constrained users to transition solely between these networks at public transport stops. Also, a delay of 0.25 min was assumed for transitions between streets and transit lines to represent boarding and alighting.

3.4 Methodology

In line with Currie (2010) and Jaramillo et al. (2012), this study aims to detect public transport gaps in Flanders by comparing public transport needs and provision. To that end, an Index of Public Transport Needs (IPTN) and an Index of Public Transport Provision (IPTP) were constructed.

3.4.1 Index of Public Transport Needs (IPTN)

The spatial distribution of socio-demographics groups (Section 3) was used to determine a general index for public transport needs. The construction of the index as proposed by Currie (2010) was taken as a basis, and the applied variables and their weightings were adapted to better suit the context at hand. In addition to variables such as age or social status, proximity to diverse primary facilities plays an important role in determining the need for public transportation. If a person has neither a car nor the financial resources to buy one, but nonetheless lives in the proximity (walking or biking distance) of primary facilities such as jobs or healthcare, then (s)he is not considered dependent on public transport. For this reason, the number of primary facilities available within walking or biking distance was included as a variable in the calculation of the public transport needs. ArcGIS was applied to calculate the distance from each TAZ centroid to the closest facilities. If this distance measured less than 1.0 or 2.5 kilometers, the facility was considered available on foot or by bicycle, respectively. These distances correspond with an average travel time of 15 minutes, which is the maximum travel time standard in Europe aimed at for more than 90% of the population (Doerner et al., 2007).

To derive an index of public transport needs for each TAZ, a statistical approach based on factor analysis was employed. Generally, factor analysis is used to perform a dimension reduction on data: a high number of variables is reduced to a smaller group of uncorrelated components (Jaramillo et al., 2012). Here, analogous to similar studies on transport disadvantage (Jaramillo et al., 2012; Kamruzzaman & Hine, 2011), the components were used to eventually calculate a single index per zone. The resulting IPTN is based on the correlation between the variables and accounts for a large part of the variance between the zones. Those variables that contain the largest variation across different areas are assigned the highest weights. Consequently, factor analysis reveals the underlying structure of the data based on the variables' high correlation.

Principal component analysis was used as the extraction method (Table 5). Three components with a strong correlation with the first principal component were selected by applying the latent root criteria for the number of components, indicating characteristic values (eigenvalues) larger than 1.000. These components individually explained more than 10% and cumulatively more than 55% of the total variance of the data. Subsequently, the three extracted components were rotated using the Varimax Rotation method with Kaiser normalization, with a rotation converging in four iterations (Table 6).

Table 5. Extraction of principal components from the individual variables for the Initial Solution and the Varimax Rotation method

Component	Initial Eigenvalues		Rotation Sums of Squared Loadings		
	Total	Variance explained	Total	Variance explained	Cumulative variance explained
1	1.635	23.362	1.545	22.071	22.071
2	1.338	19.120	1.374	19.626	41.697
3	1.073	15.323	1.128	16.108	57.805
4	0.886	12.655			
5	0.830	11.857			
6	0.803	11.464			
7	0.435	6.218			

Table 6. Rotated component matrix (Varimax Rotation) showing the factor loadings for each variable-component pair

Variable	Component		
	1	2	3
Walking distance	0.864	-0.060	0.150
Biking distance	0.890	0.001	-0.045
Elderly	-0.002	0.675	-0.008
Unemployed population	-0.013	0.675	-0.099
Car ownership	-0.043	0.659	0.058
Subsistence allocation	-0.017	0.131	-0.745
Children	0.067	0.089	0.731

Rotation further analyzes initial principal component analysis and aims to make the pattern of loadings more pronounced by arranging the components as much apart from each other as possible. Kaiser normalization normalizes the factor loadings before rotating them and, subsequently, denormalizes them after rotation. The factor loadings indicated that the first component had high loadings on the number of primary facilities within walking (0.864) and biking distance (0.890), hence representing the proximity to primary functions. The second component was strongly associated with the percentage of the population aged 65 or older (0.675), the percentage of the population that is unemployed (0.675) and the percentage of families without a car (0.659), which represent the inability to own and/or use a car. The third component had a high negative factor loading for subsistence allocation (-0.745) and a high positive factor loading for children (0.731). None of the variables had high loadings on more than one component (higher than 0.300). Therefore, no complex structures on extracted components occurred. Each component was weighted by its relative influence (normalized to unity) on the overall variance. Finally, an IPTN per TAZ was calculated by applying a linear combination of the factor loadings as weights for the individual variables. TAZs with a high index are considered to be relatively disadvantaged.

3.4.2 Index of Public Transport Provision (IPTP)

A spatio-temporal accessibility metric was constructed to represent the provision of the public transport network to various primary facilities for each TAZ. Transit trips through the public transport network were computed at specific times of the day and consequently represented the optimal path through the network at that particular time.

First, origin-destination cost matrices (ODCM) between the TAZ centroids were calculated in Esri ArcGIS. A cut-off travel time of 60 minutes was appointed to reduce computation time. This process was iterated every five minutes, over a time period of three hours (6 to 9am for peak hours and 11am to 2pm for off-peak hours).

In a second step, these travel times were used to determine the number of accessible opportunities for several time intervals for each TAZ. If the travel time between an origin-destination pair calculated in the first step was located within a predefined travel time interval (in this study ranging from 0 to 60 minutes with intervals every 10 minutes), the number of facilities (or the number of jobs or educational opportunities)at the destination zone were summarized:

$$A_{i,S,T} = \sum_{j} G(t_{ij}) F_{S,j} \quad (1)$$

where $A_{i,S,T}$ is the accessibility index for location *i*, for a service type *S* and time threshold *T*. t_{ij} indicates the travel time between origin *i* and destination *j*, $G(t_{ij})$ is an indicator function equal to 1 if $t_{ij} \leq T$ and $T \in$ (0 - 10, 10 - 20, 20 - 30, 30 - 40, 40 - 50 or 50 - 60 minutes). Finally, $F_{S,j}$ denotes the opportunities of facility type S at location j. As such, a number of accessible opportunities was determined per time threshold for each service type separately (the number of students, jobs, hospitals, supermarkets, administrative centers, physicians and day-care places). This process was iterated over the same temporal cross-sections as in the first step.

In a third step the accessible facilities per service type and time interval were combined into accessibility single index per TAZ. An average accessibility index was calculated by averaging values for the different time thresholds, applying higher weights for facilities closer to the origin zone:

$$A_{i,S} = \sum_{T=1}^{n} A_{i,S,T} W_T \quad (2)$$

where $A_{i,S}$ is the accessibility index for a certain service type S, n corresponds with the number of travel time intervals, $A_{i,S,T}$ is the accessibility index for a certain service type *S* at a certain time threshold *T*, and W_T equals the weight corresponding with a certain time interval *T* (in this study linearly: 6/6, 5/6, 4/6, 3/6, 2/6, 1/6 for time intervals 0 - 10, 10 - 20, 20 – 30, 30 – 40, 40 - 50 and 50 - 60 minutes respectively). This impedance function is similar to that applied by Schuurman et al. (2010) and Henry et al. (2013). Finally, an IPTP was calculated by normalizing the indices per service type to unity and calculating the average accessibility to primary facilities. TAZs with a high index are considered to have a relatively high provision of facilities. The calculation was performed for peak hours on an average weekday (Tuesday from 6 till 9 AM), off-peak hours on an average weekday (Tuesday from 11 AM till 2 PM) and off-peak hours in the weekend (Saturday and Sunday from 11 AM till 2 PM).

3.4.3 Index of Public Transport Gaps (IPTG)

The Index of Public Transport Gaps (IPTG) was computed as the difference between public transport needs and provision:

$$IPTG = IPTN - IPTP \qquad (3)$$

Both the IPTN and the IPTP were normalized in order to make the indices commensurable. The resulting IPTG allows comparison between the different TAZs in order to delineate the differences in transport gaps within and between zones in the study area. On the one hand, higher values of this index designate areas that need considerable attention in public transport planning due to an overall high need for and underprovision of public transportation. On the other hand, lower IPTG are significant for *De Lijn* (and other public transport companies) from an economic point of view as they indicate areas with a provision exceeding the need.

3.5 Results

This section explores the distribution of public transport needs and provision, and assesses the temporal variability of the latter. Eventually combining both indicators allows to identify areas characterized by a public transport gap or, in other words, areas where the public transport provision does not match the need.

3.5.1 Public transport needs and provision

Fig. 15 represents the IPTN for Flanders. TAZs with a relatively high index denote areas that are transport disadvantaged and in need of a strong provision. TAZs in the rural and suburban parts of Flanders are mainly characterized by a high IPTN, due to their specific socio-demographics and lower access to primary facilities. Relatively low IPTN are found for the urban (e.g. city center of Ghent or Antwerp) and coastal areas, mainly due to the higher number of primary functions within walking or biking distance. When the geography of IPTN is compared to the population density, the highest indices are found in the less populated areas (e.g. urban harbors of Ghent or Antwerp or rural and more peripheral areas, Fig. 16) and the lower indices in the densely populated city centers. As a result, most inhabitants reside in an area not characterized as public transport dependent.

An indication of the number of inhabitants dependent on public transport allows *De Lijn* to either determine improvements to make the public transport network more accessible in areas with higher numbers (higher frequency, more stops, etc.) or to provide alternative programs in areas with lower numbers in order to rationalize the current network (smaller taxi buses, replacement subsidies, etc.). In addition, TAZs bordering the Netherlands (north of Flanders) or France (southwest of Flanders) also exhibit high levels of IPTN. Possible border effects could occur at the study area's borders due to the absence of public transport data for cross-border travel to the neighboring countries. Because public transport in Wallonia and Brussels is taken into account, border-related limitations are not apparent for areas adjacent to these regions.

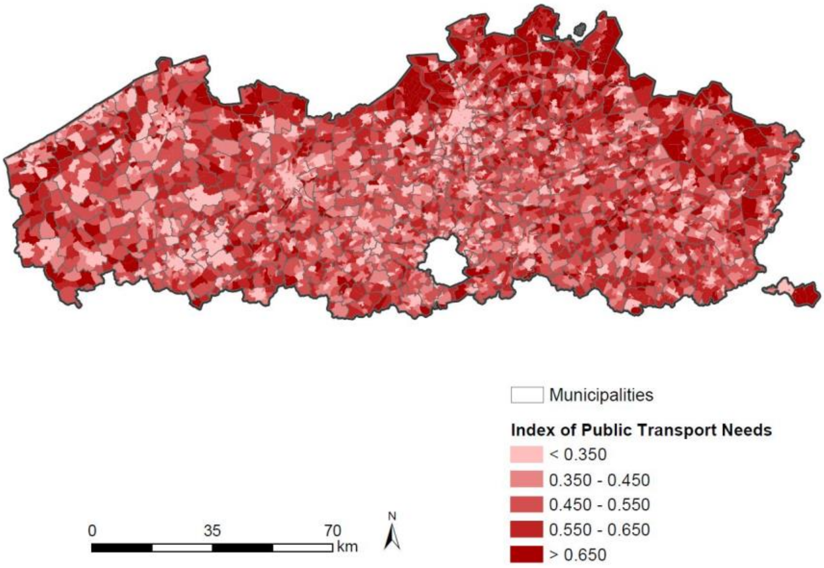

Fig. 15. Indices of Public Transport Needs per TAZ

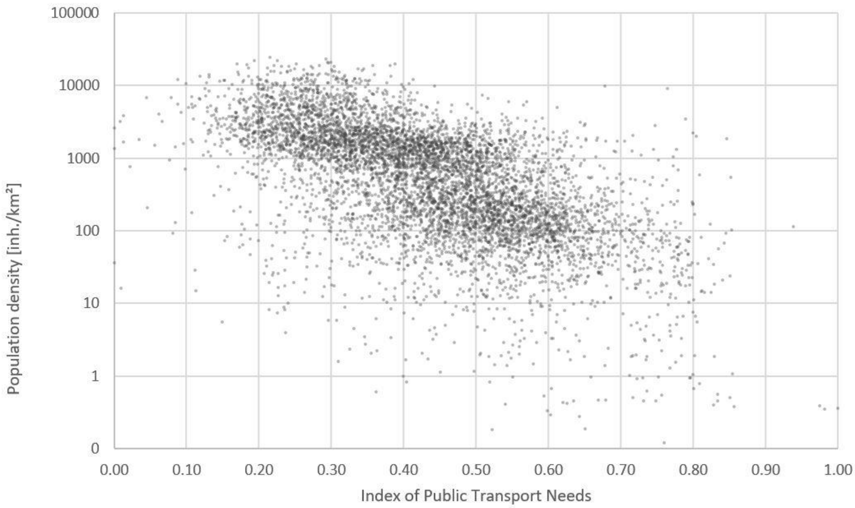

Fig. 16. The Index of Public Transport Needs in relation to the population density per TAZ

Fig. 18a shows the IPTP during morning peak hours (6 till 9 AM) on an average weekday. A high provision of primary facilities through public transport is noted in cities, due to the high proximity of facilities and availability of public transit. Analysis for various times of the week indicates a strong decline of provision by public transport for off-peak travel times, especially for suburban areas. Fig. 18b shows the IPTP during off-peak hours (11 AM till 14 PM) on a Sunday. The indices remain high in urban areas and along the railway tracks running peripherally from the larger cities. Especially Brussels and its surroundings are characterized by high indices, primarily due to the high frequency of railway to and from the city. In suburban and rural areas however, the indices are noticeably lower, which correlates with the lower transit frequencies during off-peak hours and in the weekends.

As mentioned, the IPTP varies between different temporal sections because of the strong temporal variability related to public transport. For example, on average 11% less jobs are accessible during off-peak hours than during peak hours. In addition, this index fluctuates in the considered time windows. Between 6.30 and 7 AM, the average number of accessible jobs peaks, which corresponds with the time of day that major commuting flows occur.

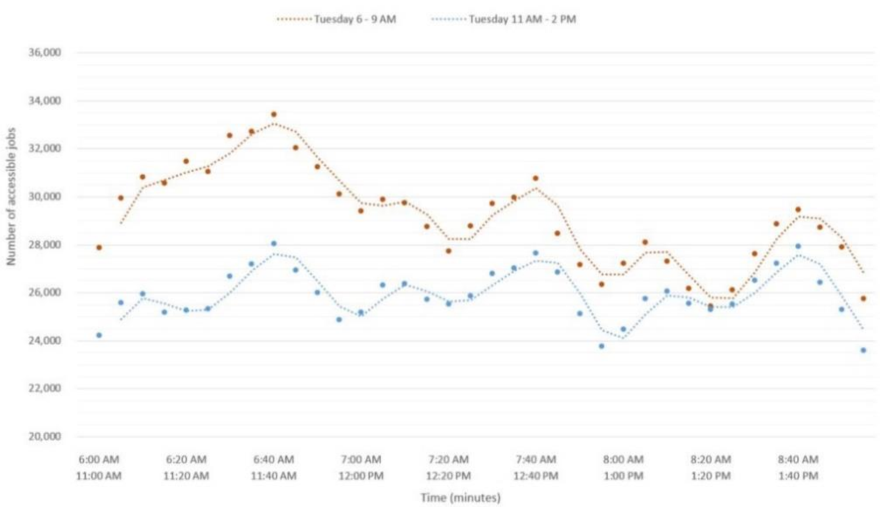

Fig. 17. Temporal fluctuations in the access to jobs during peak (6 to 9 AM) and off-peak (11 AM to 2 PM) hours on an average Tuesday

After 7 AM, this number drops as less people commute. During off-peak hours, the temporal variability is rather cyclic and corresponds to periods of higher provision every 30 minutes (Fig. 17). These results indicate that the current provision of public transport is adapted to the traditional daily rhythm of life. Moreover, they provide important information for transport companies to better align their services to these specific everyday patterns.

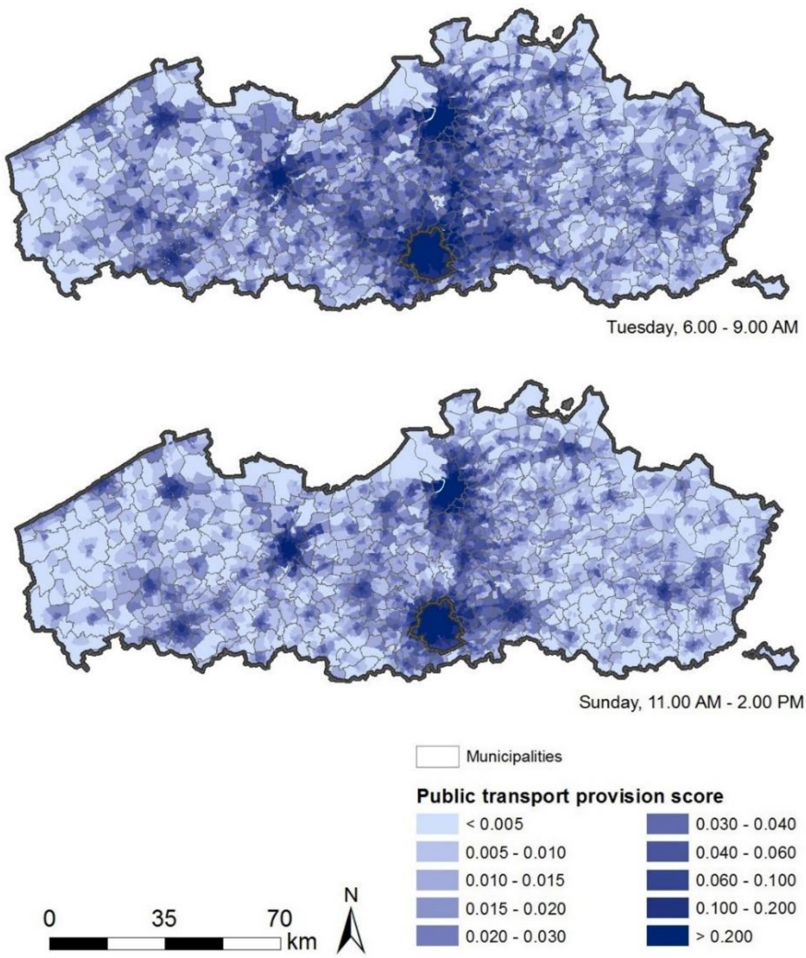

Fig. 18. Public transport provision indices per TAZ for Flanders and Brussels, for various times of the week

3.5.2 Public transport gaps

The IPTN and IPTP per zone are compared in order to define areas characterized by public transport gaps. Fig. 19 shows the deciles of lowest and highest public transport disparities in Flanders for an average weekday during peak hours. Lower indices are mainly found in urban areas while suburban and peripheral areas are generally characterized by higher gap values. The areas with lower disparities have a public transport provision in correspondence to or exceeding its need and mainly coincide with urban centers, while those with higher disparities pinpoint areas with a mismatch between the need and provision and are primarily located suburban or rural.

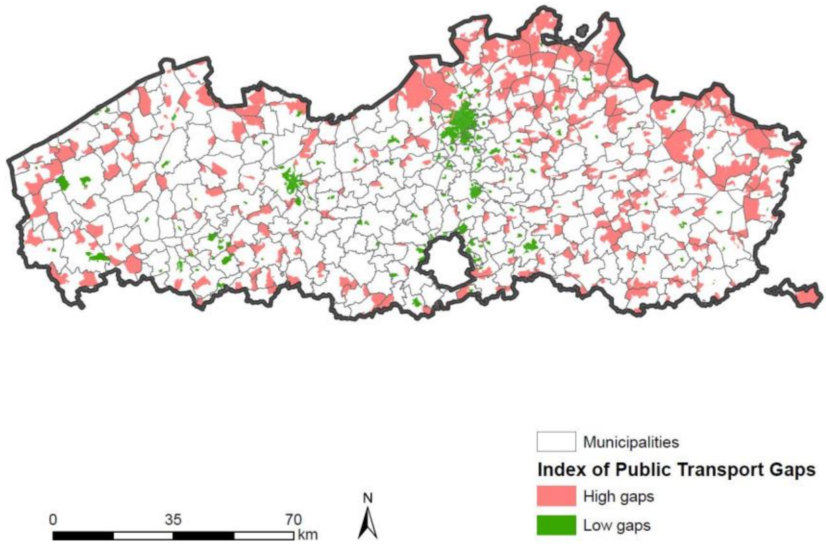

Fig. 19. Public transport gap index per TAZ for Flanders

Table 7 shows that the lowest decile spans an area of more than 2500 km^2 with an average of close to 4 km^2 per zone and is characterized by a low population density. This is in contrast with the highest decile, which contains overall smaller zones with an average area of 0.44 km^2 and a higher population density. In addition, Table 8 shows the IPTN, IPTP and IPTG for various time windows of the week for both deciles. The variances, means, minima and maxima indicate the internal variance of each decile consisting of multiple TAZs. The values in the highest decile are characterized by a high mean IPTG and high variances. The lowest decile values have a low mean IPTG with little variation between the TAZs they comprise.

Table 7. Descriptives for the deciles with highest and lowest values (N = 654)

	Average area (km²)	Total population	Average population
Low gaps	0.44	1099531	1681.24
High gaps	3.96	242686	371.08

Table 8. IPTN, IPTP and IPTG for the high-high and low-low clusters

	IPTN	IPTP		IPTG	
		Tuesday 6 - 9 AM	Sunday 11 AM - 2 PM	Tuesday 6 - 9 AM	Sunday 11 AM - 2 PM
Low gaps					
Aver.	0.2403	0.2295	0.1999	-0.0109	-0.0404
Min.	0.0000	0.0051	0.0064	-0.1298	-0.2836
Max.	0.4577	0.6337	0.5682	0.4701	0.4723
Std. dev.	0.0786	0.1198	0.1317	0.1081	0.1217
High gaps					
Aver.	0.6981	0.0107	0.0072	-0.6875	-0.6909
Min.	0.6067	0.0000	0.0000	-0.9990	-0.9990
Max.	1.0000	0.1624	0.1718	-0.6062	-0.6042
Std. dev.	0.0646	0.0160	0.0125	0.0662	0.0653

While the focus of the paper thus far has been on a generalized IPTG, the measures produced in this analysis also allow to investigate specific transit gaps for a certain type of need in respect to the appropriately related type of provision. In order to demonstrate this, the specific need for inhabitants aged 65 years and older is compared to the provision of physicians.

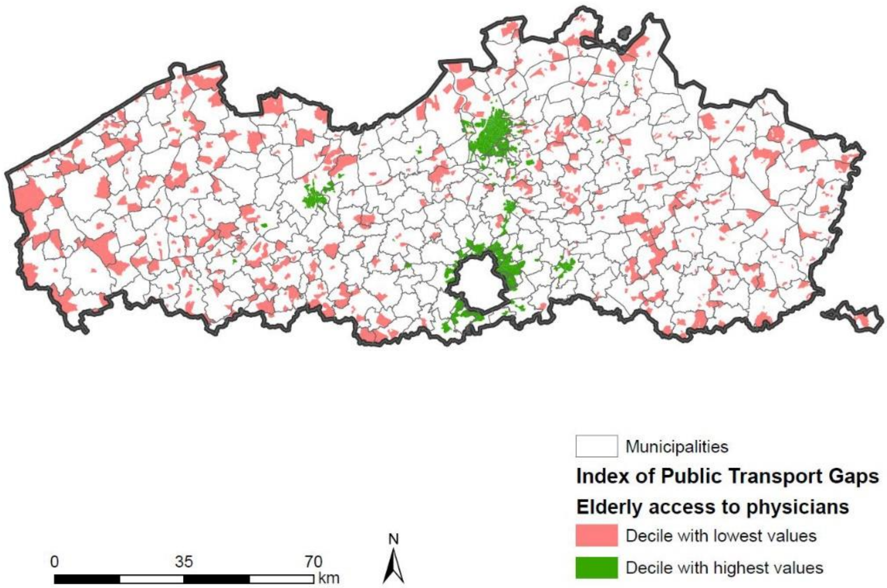

Fig. 20. Public transport gap index for elderly access to physicians per TAZ for Flanders

Fig. 20 denotes a more scattered pattern for the high gaps, with stronger concentrations of gaps in the western part. The highest values are found in the urban centers, with a stronger representation around Brussels. These types of specific comparisons can be made by transit agencies, policy makers or academics in pursuit of answers to more focused research questions.

3.6 Conclusion and discussion

This article has proposed a methodology to identify transport gaps in Flanders, Belgium. While previous studies generally do not consider the temporal variability in accessibility levels at multiple origins, this study shows the importance of modeling time-continuous, schedule-based public transport accessibility to identify public transport gaps. To that end, an index of public transport needs (IPTN) and one for its provision (IPTP) was developed. The IPTN accounted for multiple socio-demographic variables as well as spatial conditions of proximity. Several variables were weighted and applied to derive a general index of public transport needs. This index was based on the travel time through public transport to various primary facilities and was calculated over various peak and off-peak time windows for different times of the week. A higher IPTN indicated areas that strongly rely on public transport for daily transportation (e.g. rural areas), while lower indices pinpointed areas with lower needs (e.g. city centers). Although inhabitants of rural municipalities often choose a certain way of life related to a strong dependency on private means of transportation, policy tends to provide public transport for every inhabitant for multiple reasons such as environmental or social costs.

When high IPTN are accompanied by high IPTP, the provision meets the needs. However, important policy measures can be taken for areas characterized by a mismatch between both indices. From an efficiency point of view, areas with low IPTN and high IPTP can be considered as an indicator for policies aimed at reducing the current public transport provision while those with high IPTN and low IPTP denote areas where public transport provision should be reinforced or substituted by alternative actions. However, other more broadly defined objectives of public transportation (e.g., contributing to inner urban environmental quality) can support the high supply of public transport and underline a more objective stance on possible policy interventions for areas characterized by positive public transport gaps or an 'oversupply' in public transport. In urban areas, for example, an oversupply of provision provide a strong base for planning policies aimed at highlighting suitable areas to cushion the rapid population growth (e.g., in the cities of Antwerp and Ghent, and in the Brussels Rim). In addition, an oversupply of public transport provides a green alternative for cities aiming to fence cars from their city centers by, for example, introducing car free zones in their new mobility plans. The method proved to be effective for comparing different areas as well as the accessibility effects of changes in the public transport network. Additionally, the high degree of time variability within one specific time frame suggested the inadequacy of applying a single temporal section for transit-based accessibility research. However, this temporal variability was less apparent at the aggregate level of analysis, as the time of day did not strongly affect the transport gaps pattern.

While this paper represents a significant improvement of prior work in this area, at least five areas for future work can be identified. First, methodology should incorporate cross-border public transport data in the analysis. In the northern part of Flanders bordering the Netherlands, mainly low IPTG were found. However, a number of inhabitants living in these areas make use of primary facilities located outside of Flanders. Information concerning cross-border public transport as well as the location of primary facilities was not available. Therefore, indices in these area are underestimated and, relative to other analyzed TAZs, less reliable. Although data on primary facilities was also missing for day-care centers in the region of Brussels and Wallonia (both also bordering Flanders), the availability of public transport data as well as the locations of all other primary facilities was sufficient to derive a well substantiated IPTG. Nonetheless, indices in these areas are slightly underestimated. A second improvement can be obtained by augmenting the level of detail of the subsistence allocation data. Because a variable for socio-economic stratum was not at hand on the level of TAZs, in contrast to the other variables, data on the municipality level was applied in determining the IPTN. However, the socio-economic stratum is crucial in defining public transport needs (Jaramillo et al., 2012; Kamruzzaman and Hine, 2011). To this end, more detailed information concerning this variable is necessary for future studies on the subject. Third, while the calculation of public transport provision considered time variability, the method for defining public transport needs did not. Transport disadvantage also varies over time, because not all groups are disadvantaged all the time (Kamruzzaman and Hine, 2011; Wu and Hine, 2003). For example, public transport policy measures for unemployed should focus on weekday transportation in order to better link this population to possible job locations. Moreover, defining the actual number of public transport dependent inhabitants solely based on non-related variables proves to be difficult. The use of factor analysis to group the variables and weight them according to their intercorrelation seeks to address this issue. However, to delineate the population that is truly public transport dependent, more detailed information on the individual level is needed. Driver's license ownership, for example, would be a better indicator for public transport dependency than car ownership, as it is a better determinant for an individual's inability to use a car.

Mainly due to computational complexity, several assumptions were made in the calculation of the accessibility index for the IPTP. The maximum travel time of 60 minutes is not fully sufficient for public transport, especially when ingress and egress times are taken into consideration. As a result, the method tends to favor inhabitants living in the vicinity of public transport stops, as their pre and post transport remains limited. Therefore, a fourth enhancement can apply a higher maximum travel time. In addition, it seems desirable to incorporate a more accurate weighting scheme in the calculation of the accessibility index. A linear weighting scheme is highly interpretable and easy to implement and it is considered as a reasonable representation of the travel impedance when calculating travel times (Schuurman et al., 2010). Nonetheless, more complex weighting functions such as a negative exponential or Gaussian function may be considered. Finally, because the availability of public transport is an important instrument of social inclusion or exclusion, providing low tariffs and reliable service plays an important role in mode choice decision. This research did not consider tariffs for using public transportation nor measures of delays or on-time performance. It seems fruitful to incorporate these refinements into future research on public transport accessibility.

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Chapter 4: Job seekers' access to job openings in Flanders

Poor, low-educated unemployed often live in the city center, whereas a large part of the jobs relocated to the suburbs or even farther. In addition to the already existing skill mismatch, this phenomenon has resulted in significant spatial barriers between the labor market and the job market.

Yingling Fan, 2014

This chapter is adopted from the following journal article: Fransen, K., Deruyter, G., De Maeyer, P. (Under Review). Examining transport disadvantages in employment opportunities: the impact of education level and driver's license ownership on job seekers' access to job openings, *Case Studies on Transport Policy*.

Abstract

Recent decades, lower educated job seekers are reported to have difficulties entering and maintaining a job and, therefore, are more prone to long-term unemployment than individuals with a higher education. This dichotomy has a strong impact on the quality of live and economic security, and connecting disadvantaged individuals to employment opportunities is considered a vital part of social inclusion strategies. Therefore, the education gap is commonly addressed in labor policies that focus on the interrelation of various factors such as education, age, gender or migration background. Moreover, unemployed job seekers' inability to find a suitable job is strongly interwoven with transport-related issues and, more specifically, the inability to use a private motorized vehicle. This is enhanced by the strong concentration of low-skilled jobs in business parks outside of the cities or along motorway corridors. The hypothesis is that the growing, post-World War car dependency and the associated dispersed land-use pattern as well as the education gap significantly impact job seekers' opportunities and the spatial mismatch in job accessibility. To date, however, there is no clear understanding of the relationship between these disadvantaged population groups and multimodal job accessibility, and, therefore, no specific transport or planning policies address this issue. This paper aims to answer this limitation by examining the impact of driver's license ownership and education level on job seekers' spatio-temporal access to employment opportunities. The results show that driver's license ownership strongly shapes inequities in access to opportunities, as overall accessibility levels are higher for individuals who own a driver's license. In addition to driver's license ownership, lower education levels are significantly associated with a lower access to opportunities. The degree of inequity, however, is related to the opportunity's specific job domain. These results provide a crucial background in understanding the spatial mismatch between job seekers and job openings for the study area, while focusing on the most vulnerable population groups. This has important ramifications for transport policies focusing on equity in job accessibility as well as spatial planning policies that address how the future Flemish urban landscape should ideally evolve.

Keywords: accessibility; social exclusion; employment; education gap; car dependency

4.1 Introduction

Since the rise of the automobile industry in the late 20th century, society has become strongly dependent on individual, private motorized transport for daily travel. In the majority of the western countries, this car dependency has radically peaked between 1980 and 1990, whereas the possible development of a sustainable public transport system was rarely explored (Kenworthy and Laube, 1996). During these decades of automobile growth, physical planning has mainly focused on adapting the built environment to the notion of streets and public spaces as being primarily reserved for travel by private motorized transport. Norton (2008) denominates this phenomenon in urban areas as the emergence of 'automotive cities': car-dominant systems in which the streetcar has been replaced as the principle mode of urban passenger transport. This resulted in the car evolving from a minority form of transport for the privileged few to a popularized good that is considered indispensable to carry out basic daily activities (Anable, 2005; Lucas, 2006; Beirão and Sarsfield Cabral, 2007). Consequently, the concept of proximity was disregarded and overall travel distances generally increased. This build-up in action radius has encouraged and, eventually, confined the current dispersed land-use patterns as well as the car-oriented (peri)urban size and form, nowadays characterized by urban sprawl, spatial mismatches and a decreased potential for transit-based or bicycle-oriented developments.

A high automobile dependence evidently has significant impacts on the different aspects of sustainable development. As the road infrastructures' capacity loads continue to grow, an inclining number of urban areas is combatting problems of gridlocks and, consequently, its negative impact on producers of economic goods and services (e.g., businesses or local economies). Weisbrod et al. (2003) illustrate the economic implications of congestions, which raise the production costs by effectively shrinking business market areas and reducing agglomeration economies for larger urban areas. From an environmental point of view, the high number of cars strongly affects the living environment and overall quality of life. Car emissions lead to air pollution, which causes various acute and chronic health effects (Dewulf et al., 2015; Degraeuwe et al., 2016). Moreover, evidence linking car use to the increasingly detrimental effects of global warming is piling up (Uba and Chatzidakis, 2016). Both the economic and the environmental externalities related to motorized transport have been thoroughly examined and are often subject of policies striving to enhance transport sustainability. However, a high car dominance and the corresponding sprawled land-use additionally have various social implications. Inhabitants without a privately owned vehicle – or those unable to use one – are in a disadvantageous position, as they are more likely to be excluded from a basic level of access to primary opportunities, such as health care, education or employment (Preston and Raje, 2007; Stanley and Lucas, 2008). Cervero et al. (2002), for example, indicate car ownership as an important factor in connecting unemployed, under-privileged inhabitants to work opportunities. In a study for the Paris Region, Korsu and Wenglenski (2010) highlight the relationship between low job accessibility and an increased risk of long-term unemployment. This effect is enhanced by the public transport system struggling to provide similar degrees of freedom as well as a comparable level of access to opportunities as the private motorized vehicle. The bicycle – or an analogous active mode of travel – provides similar degrees of freedom as the car, as it is not linked to fixed service schedules and can also be privately owned. Nonetheless, the lower travel speed as well as aspects of travel safety and comfort continue to make the private motorized vehicle the more favorable option, even for relatively small distances. In addition, active modes of transport are not available to everyone, as elderly or those with disabilities might not be able to use them (Paez et al., 2007; Titheridge et al., 2009; Lucas and Jones, 2012). To this point, these social implications related to car dependency – be it car deprivation (Delbosc and Currie, 2012) or forced car ownership (Currie and Senbergs, 2007) – and their impact on the labor market have remained understudied. Recent years, the externalities related to car use have given rise to a more critical view on private motorized vehicles as the main means of transport. Public transport and active transport modes are not only considered to provide an alternative to the highly congested (peri)urban road networks, additionally, they are often regarded as a 'green' alternative for the car because of their lower environmental impact per capita. The question remains, however, to what extent these individuals reliant on alternative transport modes have the ability to reach sufficient opportunities in comparison to those with access to private motorized transport.

This paper continues with a background section on the dichotomy between lower and higher educated job seekers as well as the impact of transport-related issues in finding and keeping a job. In addition, this section briefly explores how accessibility analysis can aid in examining modal disparities and, correspondingly, the degree of social exclusion risks. In the following section, the methodology for measuring job seekers' spatio-temporal accessibility to job openings by various transport modes is explained. This accessibility level reflects an individual's ability to reach job opportunities, and is related to his or her education level and driver's license ownership. The results section addresses the hypothesis that a lower education level and the inability to use a private motorized vehicle are associated with a lower access to employment opportunities. Finally, the discussion section evaluates the ramifications for transport and urban planning policies.

4.2 Background

4.2.1 Educational attainment, employment and social inclusion

In light of the European Commission's strategy to reduce the number of socially excluded individuals in Europe by 20 million by 2020 (Ajwad et al., 2013), employment is acknowledged as one of the primary focal points for a wide range of policies (e.g., housing, labor or antipoverty policies). Being employed is considered as the best defense against social exclusion, and having a good education maximizes an individual's probability to find a suitable job (Social Exclusion Unit, 1999). Recent decades, lower educated job seekers are reported to have difficulties entering and maintaining a job and, therefore, are more prone to long-term unemployment than individuals with a higher education: in 2016, only 44.8% of the active population (15 to 64 years) in the European Union with a low educational attainment (less than primary, primary and lower secondary education, levels 0-2 International Standard Classification of Education) was employed, which is in sharp contrast with the high employment rate of 83.4% for individuals with a high educational attainment (tertiary education, levels 5-8 International Standard Classification of Education) (Eurostat, 2016). As a result, this disadvantaged population group of low educated job seekers is the main target considering the goal to provide an equitable access to more and better jobs. A number of studies and reports have examined the link between education, employment and various socio-demographics such as age (Mourshed et al., 2014), race (Carnevale, 1999), disabilities (Shattuck et al., 2012) or gender (Klasen and Lamanna, 2009). However, access to suitable jobs plays an important role in employment. Gao et al. (2008), for example, demonstrate the causal connections among job accessibility and employment in Sacramento County, CA, using a structural equation model. For the New York and New Jersey metropolitan area, Ozbay et al. (2006) validate that improved accessibility positively affects individuals' tendency to enter the labor market and that this effect varies across employment types and industries. As a result, unemployed job seekers' inability to find a suitable job is strongly interwoven with transport-related issues and, more specifically, the inability to use a private motorized vehicle. In the UK, for example, two out of five unemployed job seekers ascribe the difficulties to find a job to the inability to use a car and insufficient public transport provision (Social Exclusion Unit, 2003). These findings indicate a strong relationship between educational attainment, employment, accessibility and the ability to fully participate in our society.

4.2.2 The role of accessibility analysis in delineating social exclusion risks

In tandem with the wider policy interest in the notion of transport poverty – and the foundation of the Social Exclusion Unit (SEU) in the United Kingdom in 1997 – transit has largely been linked to social exclusion through the concept of accessibility planning (Lucas, 2006; Lucas, 2011). To the authors' knowledge, no large-scale study on active transport modes' accessibility levels and how they compare to the access by car is available to date. On the contrary, an extensive body of literature aims at quantifying the extent to which public transport provides access to primary goods and services. Mavoa et al. (2012), for example, determine the potential access to disaggregate destinations in Auckland, New Zealand, through the public transport system in combination with walking. The authors highlight the importance of including all components of the public transit journey in transit provision analysis. Moreover, the temporal restrictions related to transit (e.g., fixed departure times, inadequate connections or waiting times) play an important role in determining the transit service both on the trip and the trip chain level (Vande Walle and Steenberghen, 2006). Therefore, a transit network is needed that accounts for the transit schedules, a geographic road network for pre and post transport, and a link between this network and the public transport stops. In a study on the accessibility of transit services in Santa Barbara, California, Lei and Church (2010) propose an extended geographical information systems (GIS) data structure that focuses on the perspective of the potential rider by incorporating time constraints and timing issues into the accessibility analysis.

Recent years, more sophisticated accessibility measures consisting of high-resolution spatio-temporal public transport models that take into consideration every component of a public transport trip have emerged (Tribby and Zandbergen, 2012; Owen and Levinson, 2015): the pre transport from the origin location to the public transport stop (ingress), the waiting time at that stop, the time to enter or exit the vehicle, the actual public transport schedule-based travel time (including transfers) and the post transport from the last stop to the destination location (egress). The use of General Transit Feed Specification files (GTFS) has increasingly benefitted the construction of fully routable, GIS-based multimodal public transport networks, as it enables travel time analysis based on published time schedules at various temporal sections (Hadas, 2013; Farber et al., 2014; Fransen et al., 2015; Widener et al., 2015). Another way of evaluating the equitability of a public transport system, is by assessing the distribution of benefits generated by that system, especially in relation to the provision quality of the car road network (Kawabata and Shen, 2007; Gao and Johnston, 2009; Benenson et al., 2011; Salonen and Toivonen, 2013; Golub and Martens, 2014). Efforts to narrow the disparities are considered to not only help people without private vehicles, but also people who prefer public transport over other transport modes or cannot readily use cars or active transport modes. Welch and Mishra (2013), however, argue that equity measures aimed at combatting social exclusion are often ignored in transport planning. Resultantly, planning efforts primarily remain focused on the large group of car users, which further confines the overall car dependency and higher social exclusion risks for certain population groups dependent on alternative transport modes.

4.2.3 The context of Flanders and the Brussels Capital Region

European regions have generally experienced a smaller growth in car use than American areas and, moreover, hold several examples of successful cycling-focused initiatives or transit-oriented developments, and policy measures leading to higher levels of bicycle or transit use, especially in monocentric, compact cities (e.g., major cities in the Netherlands, Germany or Denmark). Nonetheless, Belgium is considered as Europe's most congested country in terms of hours wasted or delays (Christidis, 2012). Especially the polycentric region of Flanders is of ill repute for its high car ownership and usage. The Environmental Implementation Report for Belgium indicates that 75% of all Flemish commuters still use private cars. Despite being one of the only regions in the world where the right to basic public transport provision is guaranteed by law (decree '*Personenvervoer*'), public transport in Flanders is not commonly considered as an adequate alternative to the car. For the Brussels-Capital Region, the percentage of commuter traffic made by car is 55% (European Union, 2017). In the Netherlands, for example, the modal share of car use for commutes does not exceed 45% and public transportation and bicycle use is more than twice as high as in Flanders. However, transport policy efforts aim to delineate concentrations of employment as possible public transport hubs (Ruimte Vlaanderen, 2017). In addition, the recent construction of a large number of cycling corridors as well as government incentives for active travel commutes indicate a positive evolution in terms of promoting alternatives to private motorized transport.

Due to its central geographic location and highly developed (international) transport network, the region of Flanders and the Brussels Capital Region are of major importance in the European economic structure. However, economic activities are distributed unevenly, with major concentrations of specialized jobs in the central labor market core and clustering of generic, industrial jobs in the western part of Flanders (van Meeteren et al., 2016). The domain of services, for example, is mainly concentrated in the Brussels Capital Region and is the primary focus of the Belgian economy, as it accounts for 74.9% of the GDP.

4.3 Study area and data

Flanders is a densely populated region in the northern, Dutch-speaking part of Belgium, with 6.44 million inhabitants in 2015, in an area of 13,522 km^2. The Brussels Capital Region (BCR) is a very dense and fast-growing region with 1.18 million inhabitants in 2015, living in an area of 161.38 km^2. The study area consists of 327 municipalities – 308 in Flanders and 19 in the BCR – and 6,757 traffic analysis zones (TAZ), which are more detailed in the urbanized environment and larger in the less populated areas. The focus of this research are the 481,250 and 101,091 inhabitants that were registered as job seeker in 2015 in Flanders and the BCR, respectively. The data on job openings and job seekers for 2015 for Flanders as well as their socio-demographics were provided at the TAZ level by the Flemish Employment and Vocational Training Agency (*Vlaamse Dienst voor Arbeidsbemiddeling en Beroepsopleiding* or VDAB), which is the public employment service for the region of Flanders. Information on the number of job seekers (101,091) for the BCR was provided by Actiris, the public employment service for this region. This data was established on the municipality level and, resultantly, does not contain detailed information on socio-demographics on the TAZ level. Fig. 21 (top) highlights that the job seekers live strongly dispersed throughout the study area with higher concentrations in the suburban regions just outside the major city centers, especially Ghent and Antwerp.

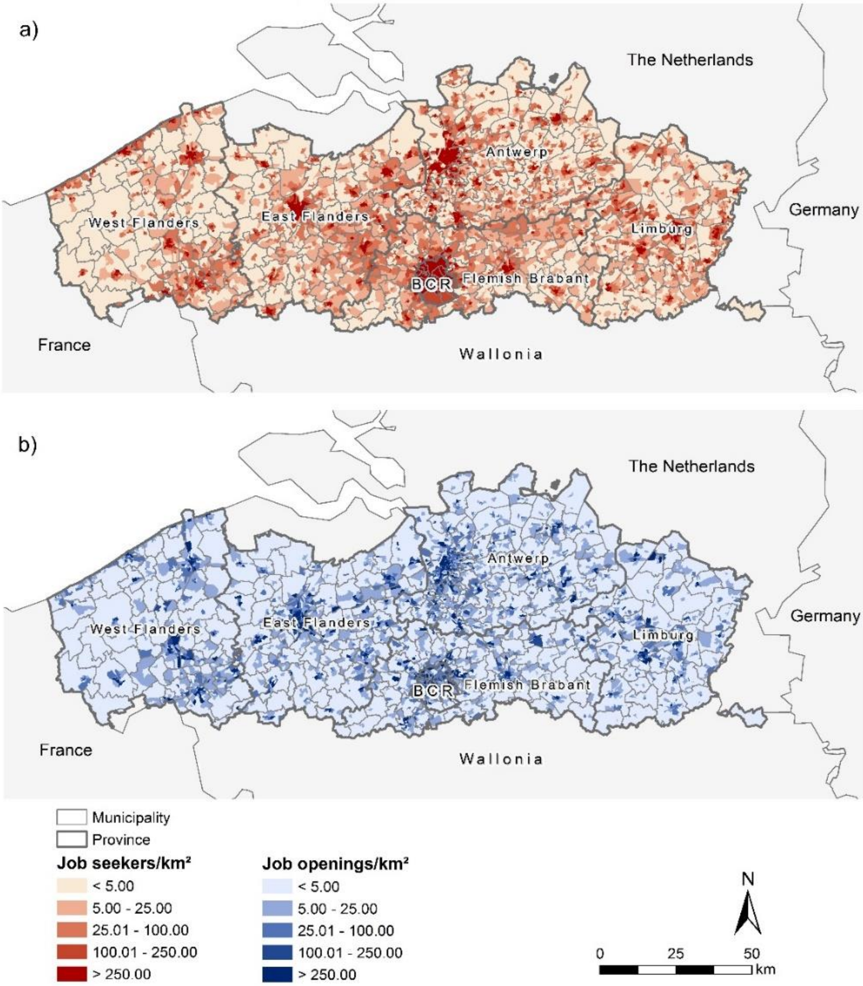

Fig. 21. a) Active population and b) employee density per TAZ in Flanders

Spatially, the job openings are highly concentrated in the most urbanized areas. A large number of rural and peri-urban areas situated in between the larger cities are characterized by a low number of job openings yet a higher number of job seekers, which could indicate a spatial mismatch in job accessibility (Fig. 21, bottom). At first glance, this mismatch related to the strong dispersed land-use pattern would be the main challenge in connecting job seekers to possible opportunities. The job openings for the BCR were added to the analysis, as a large number of inhabitants in Flanders work in the capital, especially in specialized jobs.

Table 9. Distribution of job openings per province, job domain and required educational level

Distribution	Number	Percentage
Province/region		
Antwerp	167,630	22.29%
Brussels Capital Region	60,227	8.01%
East Flanders	167,600	22.29%
Flemish Brabant	73,644	9.79%
Limburg	77,910	10.36%
West Flanders	205,055	27.27%
Job domain		
Construction	71,323	9.51%
Education and Health Care	36,249	4.84%
Industry	209,054	27.89%
Retail and ICT	235,508	31.42%
Services	82,396	10.99%
Transport and logistics	83,510	11.14%
Not specified	31,626	4.22%
Required education		
Primary + first level secondary (low)	25,428	3.38%
Second level secondary (low)	39,450	5.25%
Partial professional secondary (low)	949	0.13%
Apprenticeship (low)	2,103	0.28%
Third and fourth level secondary (medium)	220,200	29.28%
Higher professional (medium)	6,581	0.88%
Bachelor (high)	144,347	19.19%
Master (high)	46,277	6.15%
No requirements	266,730	35.47%

Table 10 shows that most job seekers are found in the provinces of Antwerp and Flemish Brabant, and the BCR, which indicates a stronger competition for job opportunities in these areas. The socio-demographics indicate a substantial representation of population groups at risk, as almost 35% of Flemish job seekers does not own a driver's license and nearly 40% has a low educational attainment. In addition, the share of low-educated job seekers is higher for the group of individuals without a driver's license (52.58%) than for those with a driver's license (32.92%). In 2015, there were 752,066 job openings in the region of Flanders and the BCR. Table 9 illustrates that most job openings are found in the provinces of Antwerp, East Flanders and West Flanders. The largest part of job openings are in industry or retail and ICT, which are also the most preferred job domains for job seekers (Table 10).

Table 10. Distribution of the number of job seekers per province in Flanders and the Brussels Capital Region (BCR) and socio-demographics for the job seeker population in Flanders, 2015

Distribution (Flanders and BCR)*	Job seekers	Percentage
Province/region		
Antwerp	156,269	26.88%
Brussels Capital Region	101,085	17.39%
East Flanders	70,581	12.14%
Flemish Brabant	109,393	18.82%
Limburg	67,617	11.63%
West Flanders	76,311	13.13%
Socio-demographics (Flanders)**	Job seekers	Percentage
Driver's License		
No	164,077	34.09%
Yes	317,173	65.91%
Education		
Primary + first level secondary (low)	84,422	17.54%
Second level secondary (low)	88,120	18.31%
Partial professional secondary (low)	8,909	1.85%
Apprenticeship (low)	9,228	1.92%
Third and fourth level secondary (medium)	184,019	38.24%
Higher professional (medium)	5,691	1.18%
Bachelor (high)	59,052	12.27%
Master (high)	41,809	8.69%
Age		
Under 18	3,227	0.67%
18 - 24	128,391	26.68%
25 - 34	133,486	27.74%
35 - 54	163,809	34.04%
55 - 64	52,167	10.84%
65 or older	170	0.04%
Gender		
Female	226,312	47.03%
Male	254,938	52.97%
Immigrant***		
No	369,127	76.70%
Yes	112,123	23.30%
Preferred job domain		
Construction	35,012	7.28%
Education and Health Care	47,899	9.95%
Industry	106,142	22.06%
Retail and ICT	135,983	28.26%
Services	104,003	21.61%
Transport and logistics	49,003	10.18%

* All 582,341 job seekers in Flanders and the Brussels Capital Region

** All 481,250 job seekers in Flanders

*** Current or previous nationality non-EU

Three types of network datasets were used to address the travel times for various transport modes in the accessibility measure. For bicycle travel, an OpenStreetMap network dataset was composed. A constant speed of 15 km/h was assumed, which is slightly slower than empirical evidence suggests in order to account for the wide variety of age groups in the dataset (Broach et al., 2012). The network is static as it does not incorporate travel time delays due to traffic congestions or traffic lights. However, temporal variations are pivotal as the access to job opportunities is a reflection of the location people might eventually commute to on a daily base (mostly during peak hours). Therefore, a routable and time-dependent transport network was constructed for both public transport and travel by private motorized transport. The 'Add GTFS to a Network Dataset' tool developed by Esri's Network Analyst Team was used to create a transit network that combines time schedules and actual public transport routes with an OpenStreetMap street network that accounts for the pre and post transport on foot. A walking speed of 4 km/h was assumed, which corresponds to an adult's average walking speed (Ritsema van Eck et al., 2005). The time schedules were based on General Transit Feed Specification files (GTFS) – which are freely available through iRail (Tiete and Colpaert, 2016) – for various transit options: *De Lijn* for bus and tram in the region of Flanders, *Transport en Commune* (TEC) for bus and metro in the region of Wallonia, *the Maatschappij voor het Intercommunaal vervoer in Brussel* (MIVB) for tram, bus and metro in the Brussels Capital Region and the *Nationale Maatschappij der Belgische Spoorwegen* (NMBS) for train in Flanders, Wallonia and the Brussels Capital Region.

Historical speed data was provided by TomTom to construct a similar time-variable network for travel by private motorized transport (small scooters or mopeds with limited maximum travel speeds are not taken into account in the private motorized transport network). Travel times are based on actual average travel speeds instead of freeflow theoretical speeds by applying weights to the various road segments according to the time of day. Resultantly, this leads to distinctly lower average travel speeds during peak hours, especially around the larger city centers (Fig. 22).

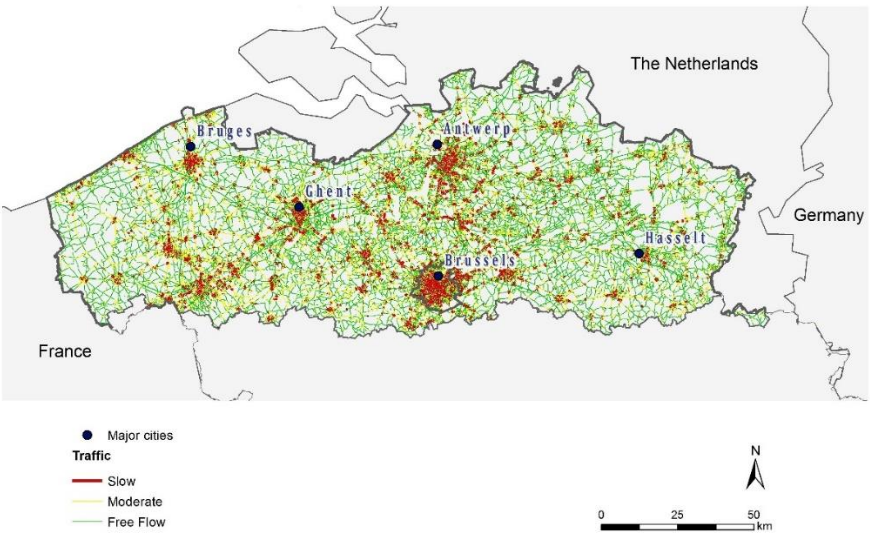

Fig. 22. Average daily traffic situation for the time-dependent private motorized transport network based on TOMTOM historical speed data for Flanders and the BCR

4.4 Methodology

Both the public and private time-dependent network were used to calculate a spatio-temporal accessibility level to job openings per TAZ. An origin-destination cost matrix (ODCM) with the travel times between all TAZ centroids was calculated for both modes. This calculation was repeated every 10 minutes from 5 AM to 11 PM, resulting in 108 ODCMs per travel mode. Because the bicycle network was not time-dependent, only one calculation was needed to construct the ODCM for the cycling travel times. First, the degree of job competition per job domain was determined for each zone based on the proportion of job seekers with or without a driver's license in its catchment area and their respective mode-based travel time:

$$C_{j,d,T} = \sum_{k \in t_{jk} < t_0} \alpha_k \, F(t_{jk,T,pmt}) S_{k,d} + (1 - \alpha_k) \frac{F(t_{jk,T,pt}) S_{k,d} + F(t_{jk,T,b}) S_{k,d}}{2} \qquad (1)$$

where $C_{j,d,T}$ is the job competition factor for TAZ centroid j for job domain d at temporal section T, t_{jk} is travel time from TAZ centroid j to TAZ centroid k, t_0 is the cutoff travel time, α_k is the proportion of individuals owning a driver's license and reflects the distribution of transport modes for TAZ centroid k, $F(t_{jk,pmt})$ $F(t_{jk,pt})$ and $F(t_{jk,b})$ are the negative linear weight functions based on a mathematical function of the travel time from TAZ centroid j to TAZ centroid k for private motorized transport, public transport and bicycle, respectively, and $S_{k,d}$ are the number of job seekers at TAZ centroid k for job domain d. Accounting for the number of job seekers within a manageable travel time of the destination zones ensures that the analysis directly incorporates spatial competition for each specific job domain and for all temporal sections. The best fitting weight function for the various transport modes was estimated by using actual travel times from the Flemish Research on Travel Behavior 2008-2013 (*Onderzoek Verplaatsingsgedrag Vlaanderen*), which is a 5–year travel survey for 6.572 individuals in Flanders. These travel times are an indication of the actual distribution of the distance impedance for the study area and, as such, a person's willingness to travel a certain time to employment activities (Fig. 23).

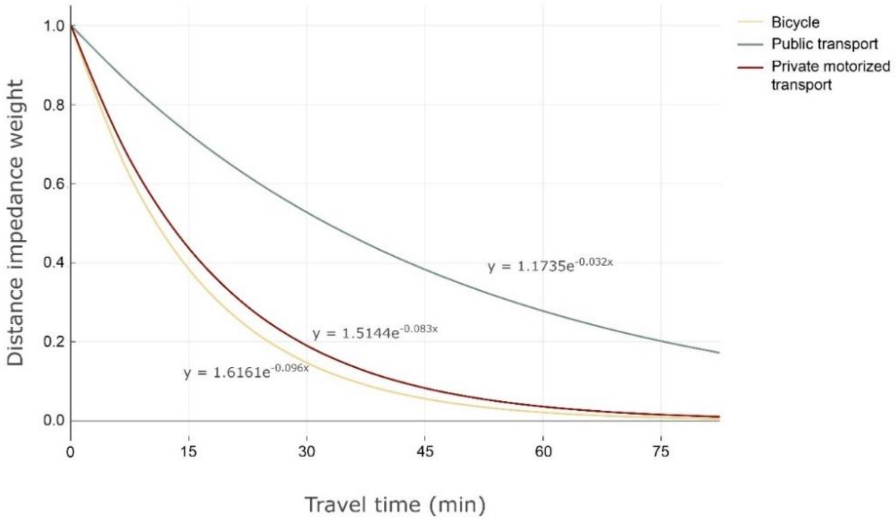

Fig. 23. Distance decay weight function for travel by bicycle, public transport and private motorized transport in Flanders based on the Flemish Research on Travel Behavior 2008-2013

In addition, a maximum travel time of 90 minutes was used in accordance with the guidelines on job seekers' travel time limits established by the public employment agencies. Second, the weighted number of accessible job openings with respect to job competition per TAZ was determined for each transport mode based on the constructed ODCMs:

$$A_{i,d,T} = \sum_{j \in t_{ij}<t_0} \frac{F(t_{ij,T})O_{j,d}}{C_{j,d,T}} \tag{2}$$

where $A_{i,d,T}$ is the accessibility level or the number of accessible job opportunities weighted by job competition at TAZ centroid i for job domain d at temporal section T, t_{ij} is travel time from TAZ centroid i to TAZ centroid j at temporal section T, $F(t_{ij})$ is the negative linear weight function based on a mathematical function of the travel time from TAZ centroid i to TAZ centroid j, $O_{j,d}$ is the number of job openings at TAZ centroid j for job domain d, and $C_{j,d,T}$ is the factor for job competition at TAZ centroid j for job domain d at temporal section T.

4.5 Results

The potential opportunities for job seekers with a driver's license is reflected by the maximized choice set for the number of weighted opportunities accessible by private motorized transport, public transport or bicycle, whereas individuals without a driver's license are unable to use private motorized transport and, therefore, are limited to the maximized choice set for solely those opportunities accessible by public transport or bicycle. An accessibility score of 1 corresponds to a sufficiency level where, considering the job competition, each job seeker has access to one job opportunity.

Fig. 24 shows the quintile distribution of the access scores related to the maximized choice sets. The share of access scores for the different quintiles indicates an inequitable distribution of opportunities, as the quintile ranges for job access for individuals with a driver's license are much higher. The range for the 20% lowest accessibility scores for driver's license owners, for example, corresponds with the range for 80% of the accessibility scores for individuals without a driver's license. Moreover, in 80% of the zones, job seekers without a driver's license cannot reach one weighted job opportunity and, therefore, fail to reach a sufficient level of opportunities. This strongly indicates the benefits achieved by being able to use a private motorized vehicle. In addition, comparison of the spatial distribution of accessibility scores highlights a more locally concentrated clustering of higher access in and around the major urban areas for access by public transport or bicycle. The BCR and the area around the city of Kortrijk in the south of the province of West Flanders are characterized by the highest number of weighted opportunities. For Brussels, the high scores are explained by the strong presence of public transportation infrastructure in combination with its central location and high number of specialized jobs. For the province of West Flanders, this is more surprising, as public transport is considered to be inefficient due to urban sprawl and long travel times. However, the high scores can be justified by a high number of job openings - especially in the domains of construction, industry and logistics - as well as a low job competition due to low population densities. This effect is enhanced for individuals who own a driver's license, as travel times are much lower for private motorized transport. Interestingly, the spatial distribution for accessibility scores for individuals with a driver's license show a high access to weighted job opportunities for the corridors that link the major urban areas (Brussels, Antwerp, Ghent and Leuven), as such, delineating the economic structure of the "Flemish Diamond". However, this urban and economic structure is absent in the distribution of access for those unable to use a privately owned motorized vehicle.

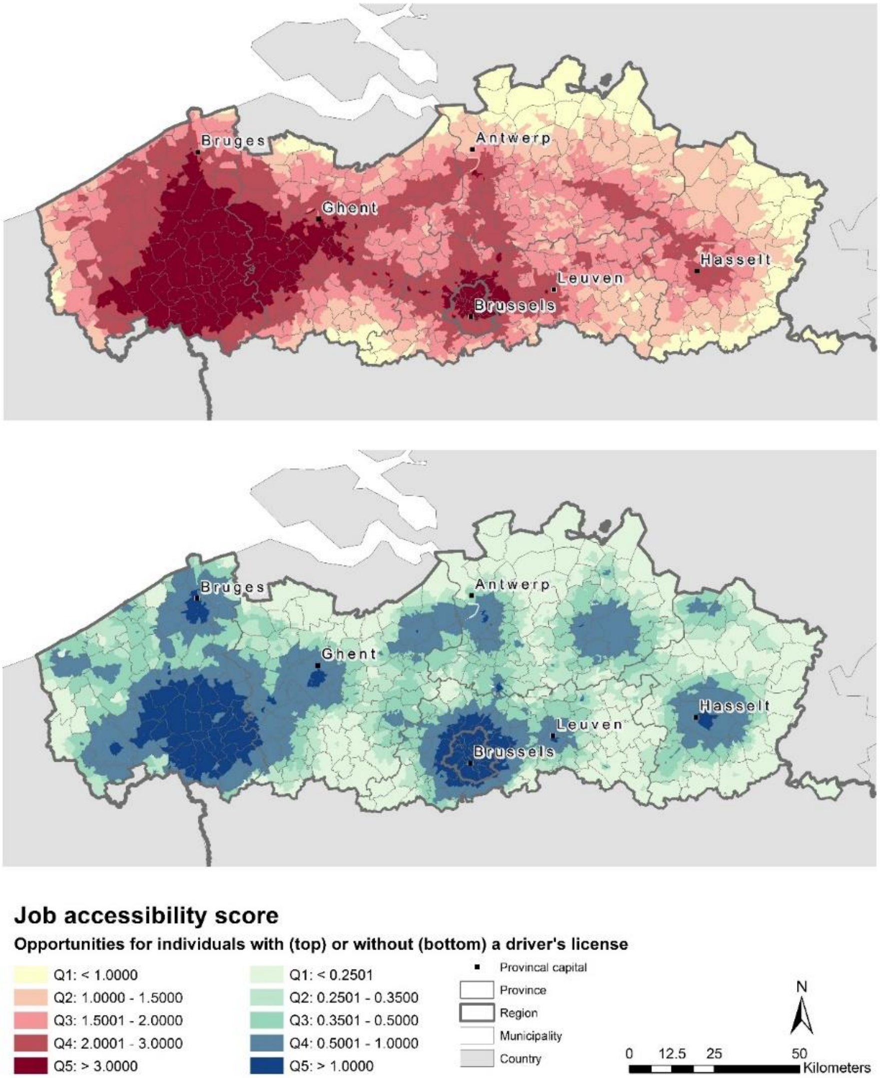

Fig. 24. Quintile distribution of accessibility scores for inhabitants with or without a driver's license in Flanders and Brussels

A general linear regression model (GLM) was used to assess the relationship between the accessibility score for the TAZ where the job seeker lives, the educational level and driver's license ownership (Table 11). Due to right skew non-normality and heteroscedasticity (studentized Breusch-Pagan test with p-value < 0.05), a Box Cox transformation ($\lambda = 0.384$) was applied to the dependent variable in the model. The GLM additionally controlled for gender, migration status, wanted job domain and age. The reference group are highly educated, male, native citizens in the age category of 35 to 54, who own a driver's license and seek a job in Retail & ICT. The results confirm the hypothesis that both educational background and driver's license ownership have a highly significant impact on an individual's accessibility to job opportunities. Considering the log link and power transformation for the estimate, job seekers with a low or medium education, respectively, have a 7% and 8% lower access than highly educated job seekers. The inability to use a private motorized vehicle to commute is strongly related to job opportunity access, as job seekers without a driver's license have access to 72% less opportunities than individuals with a driver's license. In addition, the regression model shows that other variables are significantly associated with accessibility. Gender, for example, shows a significant yet weak negative relationship, indicating that women have a 3% lower access to job opportunities than men. Job seekers with a current or previous non-EU nationality have a 16% higher access to job opportunities in comparison to individuals with EU nationality. Seeking a job in the domain of services provides the most opportunities, whereas job seekers interested in jobs in the domain of industry have the least opportunities. Furthermore, lower (under 18) and higher ages (55 or older) are negatively associated to job accessibility and have access to 4 and 1% less opportunities, respectively.

Fig. 25 confirms the findings from the regression model, as low-educated job seekers without a driver's license have lower average accessibility scores than high-educated job seekers with a driver's license. For the former, only a marginal portion of the population has an accessibility score above the sufficiency line of 1, and this is only the case for access to jobs in the domains of construction and retail and ICT. For the latter, in contrast, a minor portion of the job seekers is below the sufficiency line, which is the case for more specialized job opportunities in the domains of health care and education as well as services.

Table 11. GLM of accessibility to job opportunities in relation to various socio-demographics

Independent variable	Estimate	Std. Error	Z-value	P-value	
Education (Reference "High")					
Low	-0.0271	0.0009	-28.8770	0.0000	***
Medium	-0.0318	0.0009	-36.0090	0.0000	***
Driver's license (reference "Yes")					
No	-0.4859	0.0007	-669.3560	0.0000	***
Gender (reference "Male")					
Female	-0.0098	0.0007	-13.5050	0.0000	***
Immigrant (reference "No")					
Yes	0.0577	0.0008	74.1740	0.0000	***
Wanted jobtype (reference "Business support, retail and ICT")					
Unspecified	0.0044	0.0039	1.1290	0.2591	
Construction	-0.0031	0.0014	-2.2180	0.0266	*
Services	0.0105	0.0009	11.3800	0.0000	***
Industry	-0.0066	0.0010	-6.8490	0.0000	***
Transport and logistics	0.0024	0.0012	1.9220	0.0546	.
Education and health car	-0.0031	0.0012	-2.6240	0.0087	**
Age (reference "35 - 54")					
Under 18	-0.0168	0.0039	-4.2780	0.0000	***
18 - 24	-0.0009	0.0009	-1.0070	0.3140	
25-34	0.0113	0.0008	13.8740	0.0000	***
55 or older	-0.0055	0.0011	-4.9920	0.0000	***
Signif. codes:	*0.001 '***'*	*0.01 '**'*	*0.05 '*'*	*0.1 '.'*	

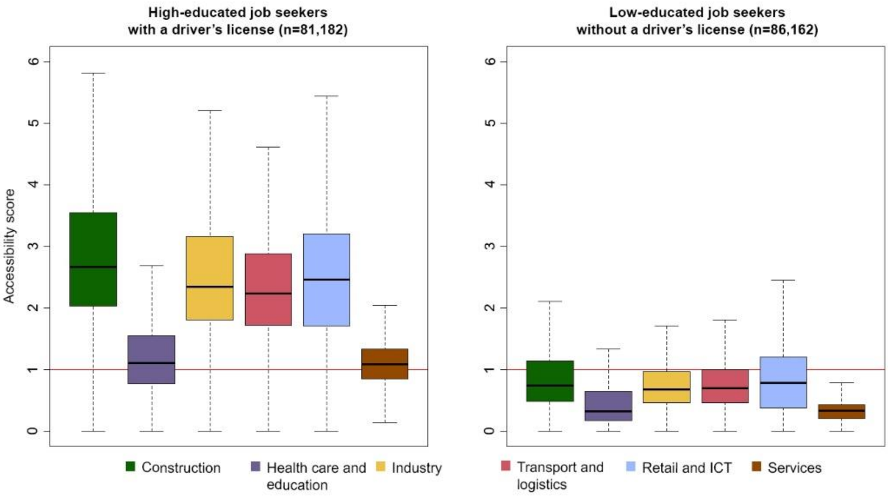

Fig. 25. Average accessibility scores for job seekers with varying education level and driver's license ownership for different job domains

4.6 Conclusion and discussion

Job accessibility and, more specifically, low educated workers' access to opportunities have been core topics in both research and policy in the domains of transportation and urban planning. In terms of social equity, low-educated, unemployed job seekers are considered to be in a disadvantage in reaching sufficient job opportunities, an effect that is enhanced by the strongly dispersed land-use pattern in a large number of European and American regions. As a result, transportation is considered as one of the major barriers in connecting individuals to employment opportunities. The proposed research aims to define the impact of the inability to use a car on access to job opportunities for low-educated, unemployed job seekers in the region of Flanders and the BCR, Belgium. Therefore, a spatio-temporal accessibility measure was constructed to identify the number of job opportunities per TAZ for different transport modes, while accounting for job competition. Subsequently, the accessibility level was related to driver's license ownership, which results in a larger choice set for job seekers with a driver's license. This larger choice set is reflected in higher accessibility scores. In addition, the spatial distribution of access scores clearly delineates the economic and urban structure of the 'Flemish Diamond' for individuals who are able to use a private motorized vehicle to commute. This pattern, however, is absent for those without a driver's license, as they are dependent on a more concentrated and local access to job opportunities. Finally, examining the relationship between a job seeker's socio-demographics and the accessibility score of the TAZ he or she lives in illustrates the negative impact of both the inability to use a car and a low educational attainment. This has important ramifications for past and present Flemish as well as European policies.

The results indicate that existing policies focusing on an equitable distribution of job opportunities for all population segments have not fully prevailed. The spatial mismatch between the economic structure and the distribution of housing denotes the importance of introducing an accessibility perspective into the analysis. This has the potential to improve the resilience of the local labor market as well as the job matching efficiency for both the region of Flanders and the BCR, and, additionally, improve the regions' pertinent roles in the international economy. Moreover, examining Flanders and the BCR simultaneously benefits job accessibility research for both regions and is often lacking in local and regional policies that address the regions as separate entities. The authors believe that understanding the interplay between factors of education, usability of (private) motorized vehicles and spatio-temporal accessibility can benefit three major policy domains. First, the results reveal the necessity to better connect job openings to job seekers, especially, for the low-educated workforce unable to use a car. Therefore, land-use and housing policies should counteract the dispersed land-use pattern by considering the existing spatial mismatches. A better understanding of the distribution and magnitude of these mismatches has the ability to support deliberate, targeted policy choices. Second, transport policies should provide more support for alternative transport modes in order to attain a more equitable distribution of employment opportunities. Increasing the usability of corridors for active transportation as well as improving the efficiency of public transport primarily benefits those population groups who are in a disadvantaged position. Third, labor policies are capable of addressing limitations on an individual level. In the employment process, benefits can be gained in providing more detailed information on an individual's transportation options. For example, comparing a job seeker's access for various transport modes and job domains in the form of a 'mobility passport' might inform the person on possible areas of training that can enhance his or her opportunities or illustrate the possible benefits of facilitating transport options (e.g., in the form of a public transport or bike sharing subscription) when this person's accessibility levels are high or low, respectively. In addition, a better informative process can highlight the increased benefits of attaining a driver's license. However, in terms of sustainability, this can inhibit transport policies focusing on a modal shift due to improved efficiency of alternative transport modes. These points may deserve to feature in future policy evaluation debates.

Although this research provides valuable insights on access to employment opportunities for disadvantaged population groups, there are some important limitations that should be addressed in future research. Most of these limitations are related to the aggregated nature of the analysis, which fails to incorporate personal aspects of travel behavior and individual preferences or competences. In this research, the absence of a driver's license is directly linked to the inability to use a private motorized vehicle. However, if an individual acts as a passenger for a colleague, partner or relative working in the vicinity, this person might have a larger choice set than assumed. Herein, car ownership is a better indicator for an individual's ability to use a car (the car is most likely an option), whereas driver's license ownership is a more strict determinant of an individual's inability to use a car (the car is most likely not an option). The proposed accessibility measure additionally does not incorporate scooters or mopeds that do not require a driver's license or shared motorized transport organized by companies. Conversely, driver's license ownership does not by definition preclude car ownership, as financial aspects can strongly influence a household's ability to own and, therefore, use a car (Dargay, 2001). Moreover, having a driver's license does not necessarily reflect an individual's personal preferences and believes, as this person might opt for other transport modes notwithstanding the lower accessibility levels, which is not reflected in the maximized choice set. In addition, this research does not account for the ability to change the residential location in order to better access a job opportunity. Considering the employment process in the study area, this is a valid assumption, as the public employment agencies only connect job seekers with job opportunities within a certain cutoff distance from their residential location. Nonetheless, a proportion of the job seekers might change their living location in order to have more opportunities, which, however, is not an evident choice for people in a disadvantaged position, as moving can have strong financial implications. Job-specific characteristics can also have an impact on job seekers' accessibility. For job seekers without a driver's license, for example, the number of opportunities is overestimated, as certain jobs require a driver's license. These limitations can only be addressed when examining accessibility to job opportunities on an individual level, which requires more detailed information on both job seekers as job openings and qualitative research on job seekers' preferences.

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Chapter 5: The accessibility-participation relationship in Wasatch Front, Utah

Not being able to participate in activities has been identified as one of the primary results of social exclusion. Herein, transport plays a crucial role because it allows inhabitants to access locations in which they can participate in an activity.

Md. Kamruzzaman, 2010

This chapter is adopted from the following journal article:
Fransen, K., Farber, S., Deruyter, G., De Maeyer, P. (Accepted for publication). A spatio-temporal accessibility measure for modelling activity participation in discretionary activities, *Journal of Travel Behaviour and Society*.

Abstract

Accessibility is a key indicator for the number of opportunities experienced by an individual, and it is generally assumed that higher levels of accessibility lead to higher levels of activity participation and satisfaction. Despite the fact that this relationship has been tested in preceding studies, no clear pattern of correlation has been found between an individual's accessibility and his/her participation in out-of-home discretionary activities. Previous studies mostly applied aggregate, spatial accessibility measures that do not account for the heterogeneity related to an individual's spatio-temporal constraints. However, in addition to locations' spatial distribution, personal constraints related to the mandatory activities a person undertakes – and therefore, his/her available time budget throughout the day – impact activity choices and scheduling. This paper proposes a disaggregate, person-based accessibility measure that takes spatial and temporal constraints into consideration for the travel behavior of 11,599 individuals in the Wasatch Front region, Utah. This method is compared to an aggregate, home-based accessibility measure to assess both methods' ability to predict activity participation. The results show a highly significant, moderate correlation between the proposed person-based accessibility measure and participants' surveyed partaking in discretionary activities. Both the model prediction and the locally weighted regression smoother indicate that the greatest change in participation occurs within the mid-range of accessibility levels, and not in the low end of the accessibility range as was expected. In addition, the home-based method shows a negative and highly significant relationship to activity participation, which indicates that aggregate accessibility measures may provide counterintuitive findings.

Keywords: accessibility; activity participation; space-time; person-based; Wasatch Front

5.1 Introduction

From the second half of the 20th century, investments in automobile-oriented transportation infrastructure have dramatically increased mobility levels (H. Miller, 2007). When considering the theory of constant travel time budgets, this higher mobility has likely led to increased trip generations, and more trips being made to destinations at greater distances (Zahavi, 1978). The literature lends support to the view that the rate at which trips are generated in a population is linked to the ease of making trips to potential destinations. This assumption coincides with some of the well-known definitions of accessibility, such as 'the potential of opportunities for interaction' by Hansen (1959) or 'the freedom of individuals to decide whether or not to participate in different activities' by Burns (1979). Moreover, since the introduction of the concept of accessibility, transport policy has established this concept to be founded on the basic economic principle of supply and demand. The provision of accessibility is deemed to lead to an increased trip generation and, therefore, a higher participation in out-of-house activities for which the general demand is high (Thill & Kim, 2005). So, there are good reasons to believe that higher levels of mobility, but really its ensuing accessibility benefits, lead to increased participation in discretionary activities and, therefore, more social inclusion for various segments of the population.

Various studies have aimed at addressing this interaction, in order to highlight the extent to which accessibility-enhancing policy decisions have the ability to generate an increase in activity participation. Until this moment, diverging correlations are found, and the empirical validation in the literature remains inconclusive on a uniform definition. In this retrospect, accessibility is often considered from a purely spatial point of view. Where the friction of travel cost is reduced, more trips to destinations at greater distances – and, potentially, more participation in activities –would be generated. However, this perspective does not take into account the inter- and intrapersonal heterogeneity related to an individual's personal constraints. From a time geographic perspective, individuals additionally have more time available to partake in certain activities at destinations at shorter distances, which could increase the utility gained from the activity or provide more flexibility in activity scheduling. Person-based accessibility metrics address a traveler's daily and long-term scheduling of their activity demands and enforced commitments by considering the location and duration of mandatory activities, the time budgets for discretionary activities, trip-chaining and travel cost (Geurs & van Wee, 2004). In the past decade, the literature on person-based or activity-based accessibility measures has burgeoned (Patterson & Farber, 2015). These metrics are founded on Hägerstrand's classical time geography and apply time-use concepts, based on the notion that time and space dimensions are interdependent and should both be incorporated in activity and travel demand models (Hägerstrand, 1970; Kwan, 1998; Lee et al., 2007). Accordingly, individuals are bound to particular locations at specific times of the day. Space-time concepts have been commonly applied to determine the opportunity to engage in activities given both spatial and temporal limitations due to land use and transportation and communication infrastructures (Fransen et al., 2015; Kwan, 1998; T. Neutens et al., 2012). To date, a large number of activity-based travel demand models exist that provide highly detailed space- and time-sensitive measures of person-level accessibility (Bhat et al., 2013; Davidson et al., 2007; Timmermans et al., 2002). Nonetheless, empirical research on the benefits of applying space-time measures of potential accessibility to predict realized activity participation remains scarce.

Validation of this conception is of crucial concern given the ongoing paradigm shift towards planning for increased accessibility, which is widely motivated by environmental as well as social justice considerations (K. Martens, 2016). Herein, zone-based measures fail to grasp all individuals' life experiences related to the full spectrum of aspects of social exclusion or transport poverty (H. J. Miller, 2006). In addition to aspects of time, various socio-demographics such as car ownership, age or disabilities influence the level of social exclusion risks a person is exposed to (Delbosc & Currie, 2011; Lucas, 2011; Preston & Rajé, 2007). A growing number of transport investments aim at increasing access to opportunities in areas with existing low levels of accessibility and neighborhoods with a low socio-economic status (SES). However, the extent to which this benefits the well-being of people living there has not been thoroughly examined. The vulnerable or impaired population, for example, has proven to be of little concern for targeted policies, despite their generally low levels of well-being in relation to transportation (Currie et al., 2010).

The motivation for this paper stems from the discussion above. A person-based travel demand analysis enables to incorporate complex travel patterns and trip-chaining behavior into the analysis. The accessibility is measured on an individual level and, as such, accounts for a person's spatial patterns as well as daily temporal constraints. The resulting disaggregate accessibility index better reflects the realized travel behavior and activity participation and, resultantly, contributes to the existing strand of literature. Introducing the socio-demographic characteristics on the individual or household level enables the identification of the various significant factors that simultaneously impact participation. In addition, it allows to highlight disparities between individuals with different socio-demographic characteristics.

The remainder of the paper is organized as follows. First, it continues with a brief background in Section 2, which highlights the inability of previous studies to determine a uniform and clear association between accessibility and activity participation, and investigates the possibilities of incorporating temporal constraints to better predict this relationship. Section 3 reports on the study area and data applied for the analysis. Subsequently, the methodology is explained in Section 4. The paper provides the major results in Section 5 and concludes with both limitations to and further research possibilities for the study in the discussion section.

5.2 Background

An extensive body of literature exists on the benefits of the provision of accessibility to generate more opportunities to reach certain destinations in a wide range of domains (e.g., health care (Dewulf et al., 2013; McGrail & Humphreys, 2009), shopping (Farber et al., 2011; Widener et al., 2015), employment (Albrechts, 2010; Owen & Levinson, 2015)). Herein, the availability of more opportunities – and therefore, an improved potential accessibility – is considered to generate more realized activity participation. However, to date, no unambiguous conclusion on this relationship can be made, as strongly diverging empirical evidence supporting as well as contradicting the significance of this relationship is available.

On the one hand, a group of studies support this claim. Koenig (1980), for example, examined the relations between a single gravity-based accessibility measure and observed trip rates for participants in different French cities, and highlighted accessibility as a powerful determinant of the trip frequency. Similarly, Purvis et al. (1996) applied a home-based model to study the impact of work accessibility on non-work trip frequency for the San Francisco Bay Area. The model showed an inverse relationship between work trip duration and home-based nonwork trip frequency. A more recent study by Thill and Kim (2005) estimated Poisson regression models of automobile trip generation by trip purpose using survey data for Minneapolis-St. Paul, Minnesota. They tested alternative measures of accessibility for statistical signifance, and found confirmation to support the theoretical arguments and empirical evidence that trip generation is related to geographical accessibility. Additionally, the authors concluded that different accessibility measures capture different facets of how individuals interact with the spatial structure and distribution of opportunities. The socio-economic characteristics of the population such as income, car ownership, household size, age and driver's license information, and even lifestyle choices have been proved to have a strong impact on both trip generation and activity participation (Krizek & Waddell, 2002). Lu and Pas (1999) composed a structural equation model to examine the relationships between socio-demographics, activity participation and travel behavior. The results showed that travel behavior can be explained better by incorporating activity participation endogenously in the model, than through socio-demographics alone.

On the other hand, a strand of research has found contradicting conclusions. In a study for Uppsala (Sweden), Hanson and Schwab (1987) used passive home-based and work-based accessibility measures to study the relationship of an individual's travel behavior to his/her location, while controlling for several socio-economic (e.g., sex, automobile availability or employment status) as well as travel variables (e.g., mode use, trip frequency or trip complexity). Especially at the intraurban scale, they concluded that higher accessibility levels were only marginally significant for most groups and not significant for female participants. Contrary to the strong trip frequency-accessibility relationship posited frequently in the literature and deductive formulations, they found that accessibility has a greater impact on mode choice and travel distance than on discretionary trip frequency. A study for 300 households in the Reading area (UK) by Downes and Morrell (1981) showed no significant correlation between household location relative to the town center and household weekday travel time budgets or trip rates. Moreover, the study indicated a linear dependency of both dependent variables on household size and car ownership. Interestingly, Cordera et al. (2016) highlight the importance of discerning between trip generation to work-related, mandatory activities and discretionary, non-mandatory activities as well as between transport modes. In their study on the relevance of accessibility in trip generation for the urban area of Santander, they found that a higher accessibility was related to a decrease in trip generation by private vehicle for work purpose, whereas it increased the trip rate to discretionary activities by other transport modes. Additionally, they bring attention to the role spatial effects between observations play.

There are several limitations to the research in the literature at hand. The most important drawback is that most studies use a zone-based accessibility measure to determine an individual's (or a household's) accessibility level. These commonly applied aggregate accessibility measures are static, in the sense that they allow only for one reference location and that they do not consider inter-personal heterogeneity. In the past, key locations such as the home or work locations played an important role in determining an individual's accessibility, as people, locations and activities were strongly linked. The increasing mobility and connectivity due to a lower friction of distance means that the relationships between people and place are becoming more subtle and complex, rendering a purely spatial perspective no longer viable. Although mobility and connectivity can fragment some activities, others remain firmly grounded in physical space (H. Miller, 2007). Person-based and spatio-temporal accessibility measures additionally encompass the temporal and individual constraints, interacting with the spatial and institutional constraints as well as the transport system (T. Neutens et al., 2010; Schwanen & Dijst, 2003). A large number of activity-based travel demand model systems in practice and under development (e.g., SACSIM (Bradley et al., 2010), the open soured openAMOS (Pendyala et al., 2012) or ALBATROSS (Arentze et al., 2000)) enable to simulate each resident's full-day activity and travel schedule. However, these models start from the premise that access is used as a predictor for activity timing, location and duration, with the means of generating activity schedules applied in micro-simulation models. In addition, the majority of the aforementioned studies focus on active mode trip generation and fail to address in detail whether higher accessibility levels lead to more activity participation, in general.

A wide range of spatio-temporal, person-based accessibility measures that use individual trip diary data are available (Kang & Scott, 2010; T. Neutens et al., 2012; Roorda & Ruiz, 2008). A large body of literature in this research domain discerns between discretionary and fixed activities to delineate a person's access to the former while accounting for mandatory anchor points related to the latter (Kim & Kwan, 2003; Tijs Neutens et al., 2010). These studies determine a person's potential activity space by relying on concepts such as space-time prisms and potential path areas, which illustrate the scarcity of both space and time. Tijs Neutens et al. (2008) proposed a three-dimensional, network-based space-time prism to address complex, real-life applications more accurately by accounting for the heterogeneity of an individual's space-time environment. More elaborate measures differ from the choice-based scenarios insofar that they analyze travel that has already occurred. Horner and Downs (2014), for example, extended the classical potential path approach and, as such, spatio-temporal analysis by incorporating the probability that certain areas are traversed by a moving object. The proposed time geographic density estimation highlights moving objects' potential for interaction by combining the fundamentals of time geography and statistical density estimation to generate a continuous density surface for person-based accessibility.

In light of this research review, previous studies investigating the accessibility-participation relationship are found to be inconclusive. This is because preceding studies have had a different focus (e.g. active mode use and trip length) and because they have primarily used aggregate measures of accessibility. This paper specifically focuses on the accessibility-participation relationship, while incorporating more valid space-time measures of accessibility as proposed in this paragraph. Therefore, the research emphasizes the social implications of activity participation instead of implications on specific travel demand. Interesting herein is whether policies aimed at increasing accessibility are likely to have benefits in terms of increased participation. This is particularly important for populations who have low levels of activity participation, either due to SES or low levels of spatial accessibility. The hypothesis is that, all else being equal, increasing accessibility for these populations will have a larger impact on activity participation than for already affluent, high-access groups.

5.3 Study area and data

5.3.1 Study area

The study area consists of the most densely populated area of the state of Utah, centered around Salt Lake City, and more specifically, the Wasatch Front region comprising of the following 11 counties: Box Elder, Cache, Davis, Morgan, Rich, Salt Lake, Summit, Tooele, Utah, Wasatch and Weber. The region has a population of approximately 2,376,370 inhabitants in an area of 62,711 km^2. Fig. 26 indicates the strong north-south directionality of the urban development, bordered by the Uinta-Wasatch-Cache National Forest and the Wasatch mountain range in the east and the Great Salt Lake and deserts in the west.

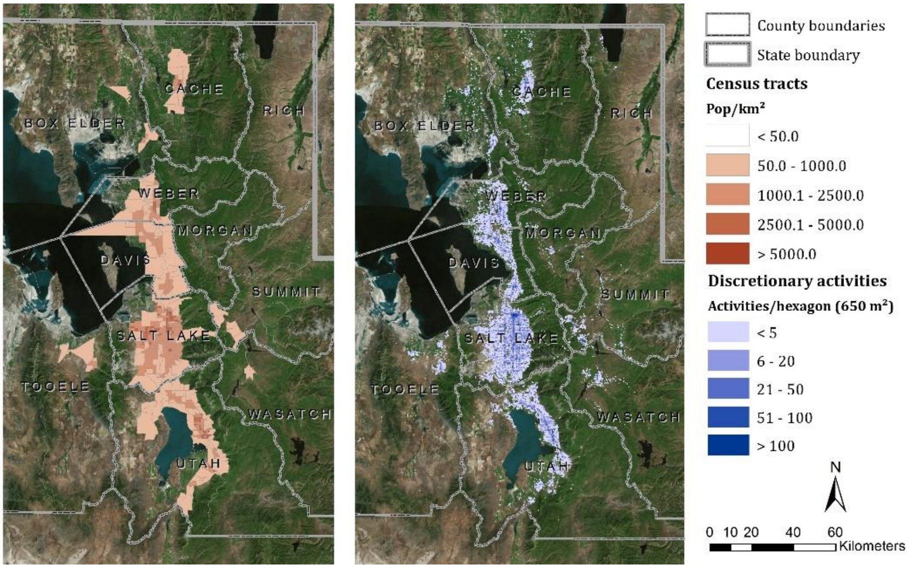

Fig. 26. Population density and discretionary activity distribution for the selected counties in Utah

5.3.2 Data

The 2012 Utah Statewide Travel Study conducted by the Wasatch Front Regional Council, Utah Department of Transportation, Cache Metropolitan Planning Organization, Mountainland Association of Governments, Dixie Metropolitan Planning Organization and Utah Transit Authority, contains the survey results for 9,155 households in Utah (consisting of 27,046 individuals, making 101,405 trips in total). Each household is asked to comprehensively report the travel that occurs for all household members over a pre-assigned 24-hour period on an average weekday (Tuesday, Wednesday or Thursday). The survey collects demographic data on the household and person level, the vehicle characteristics and the individual travel behavior. The latter served as a base for constructing a daily activity diary for each household member in the survey. Defining the fixity of various types of activities in an activity based-approach is complex, as activities can take place at different locations (spatial flexibility) and at specific times of the day (temporal flexibility), and are intrinsically characterized by interpersonal flexibility (Doherty, 2006). However, very few surveys collect details on flexibility, and it is common practice to make simple, static assumptions based on activity type reported (Schwanen & de Jong, 2008). We regard any activity in between two work- or school-related trips as well as the activity of sleeping as a subsistence or fixed activity. In addition, an activity between trips related to another household member's fixed activities, such as picking up or dropping off the children at school or childcare, is considered fixed. These fixed activities comprise of 71.7% of the total time budget, whereas other activities – the non-fixed, discretionary activities – encompass 28.3% of the time participants spent on a daily basis (Table 12).

Table 12. Number and minutes of activity for the 2012 Utah Statewide Travel Study

Activity type	Activity frequency	%[1]	Activity time (min)	%[2]
Fixed				
Drop-pickup	2,481	2.1%	48,140	0.4%
School-daycare	1,305	1.1%	224280	2.1%
Sleep	23,198	20.0%	4,871,580	45.2%
Work	6,864	5.9%	2,422,420	22.5%
Work-related	1,444	1.2%	166,275	1.5%
Non-fixed				
Exercise	1,229	1.1%	88,325	0.8%
Food	2,043	1.8%	96,490	0.9%
Home	7,815	6.7%	964,520	9.0%
Other	1,886	1.6%	151,370	1.4%
Personal-business	3,053	2.6%	135,255	1.3%
Quick-stop	1,081	0.9%	15,735	0.1%
Religious	1,455	1.3%	148,460	1.4%
Shopping	5,691	4.9%	201,195	1.9%
Social-rec	2,435	2.1%	247,045	2.3%
Travel	54,069	46.6%	994,530	9.2%

[1] *Total activity frequency per activity type / total activity frequency*

[2] *Total number of minutes spent per activity type / total number of minutes spent*

Several assumptions were made to select a representative group of individuals from the original dataset. First, the location of each activity was geocoded on the address level. Individuals with one or more activities at a location without valid coordinates were discarded. Second, to compute the accessibility measure, each individual was assumed to have a fixed sleeping activity between 11 pm and 6 am. The American Time Use Survey

(ATUS) indicates that from 11 pm until 6 am, less than 5% of the American population is working, following education or travelling for work or educational purposes. Individuals with one or more activities during this time period were excluded from the final dataset.

Third, only households in the previously described study area were retained for analysis. While the Utah Statewide Travel Study surveyed the entire state, the vast majority of the urban population resides within the Wasatch Front region studied in this paper. Fourth, individuals aged 15 or younger were removed from the dataset because of their dependence on other household members to travel and, therefore, participate in activities. Eventually, the selection resulted in a 24-hour activity diary for 11,599 individuals (in 6,798 households). The participants are predominantly White or Caucasian, non-Hispanic and highly car oriented, as more than 96% have a driver's license. In addition, more than half of the households are small households without children. The various age, gender and income groups are well-represented (Table 13).

Table 13. Socio-economic characteristics for 11,599 individuals selected from the 2012 Utah Statewide Travel Study

Socio-economic characteristics		
Age	Under 18	1.61%
	18 - 34	35.54%
	35 - 64	49.33%
	65 or older	13.52%
Gender	Female	52.38%
	Male	47.62%
Race	African American or Black	0.37%
	American Indian or Alaskan Native	0.27%
	Asian	2.05%
	White or Caucasian	92.46%
	Other	2.03%
	Prefer not to answer	2.82%
Hispanic	No	94.80%
	Yes	3.24%
	Prefer not to answer	1.96%
Driver's license	No	3.23%

	Yes	96.77%
Limited mobility	No	95.77%
	Yes	2.10%
	Prefer not to answer	2.13%
Household annual income	Under $35,000	15.45%
	$35,000 - $74,999	34.96%
	$75,000 - $149,999	31.09%
	$150,000 or more	6.93%
	Unspecified	11.57%
Number of children in household	0	52.37%
	1	14.31%
	2	14.48%
	3	10.41%
	4 or more	8.43%

The locations of the activity opportunities used in the accessibility scores were extracted from the Dun & Bradstreet (D&B) Million Dollar Database, which contains company information for privately held and public companies for primary and secondary lines of business in the U.S. and Canada. The collection was searched for business in Utah using the Primary SIC Code specialty field as criteria, resulting in 35,838 activity opportunities at the company branch level in the study area covering a wide range of points of interest for discretionary activities (Table 14). The activity locations were geocoded on the address level.

Table 14. Number and type of activity opportunities in the study area

Activity opportunity type	**Number of opportunities**
Stores	
Food stores	1,513
General merchandise	385
Miscellaneous retail	4,747
Services	
Amusement and recreation services	2,121

Depository institutions	757
Eating and drinking places	4,039
Educational services	2,494
Health services	7,870
Legal services	1,654
Membership organizations	3,133
Museums, art galleries and botanical and zoological gardens	159
Personal services	4,662
Social services	2,304

5.4 Methodology

5.4.1 Spatio-temporal accessibility measure

The spatio-temporal accessibility measure identifies the overall time a participant can spend at a range of activity opportunities throughout the day. First, both the participants' fixed activities' locations and the locations of the activity opportunities were assigned to the closest centroid in a hexagonal grid with an aerial distance of 500m between their centroids. An origin-destination cost matrix (ODCM) was calculated in Esri ArcGIS for every grid cell pair, resulting in a network-based travel time by car for each possible combination of locations. Because of the difficulty of obtaining congested travel time data, the travel cost is based on the freeflow travel by private motorized vehicle. The Texas Transportation Institute's (TTI) Annual Mobility Reports for Salt Lake city indicate the relatively low level of congestion for a city of its size, which validates the use of freeflow travel times (Schrank et al., 2015).

In a second step, these travel times were used to determine the number of accessible locations and the amount of time a participant can spend at each location, considering his/her daily schedule. A space-time prism (STP) was calculated for each time period between two consecutive fixed activities. By projecting the vertical dimension of the STP, the potential path area (PPA) was delineated, which refers to the spatial extent of where an individual can partake in activities given certain spatio-temporal constraints (Patterson &

Farber, 2015). Opportunities within this spatial extent are considered to be accessible, and the potential activity time is derived from the travel time from the fixed activity location and the travel time to the next fixed activity location. Fig. 27 shows an example of an individual with several fixed activities: sleep, dropping off and picking up children from school, and work. The participant has two opportunities to engage in activities, one in the morning and one in the evening, represented by the STPs. The projection of these STPs indicates the ability to reach none of the activity opportunities in the morning and one opportunity in the evening. The time the participant can spend at that location is represented by the red space-time path in Fig. 27.

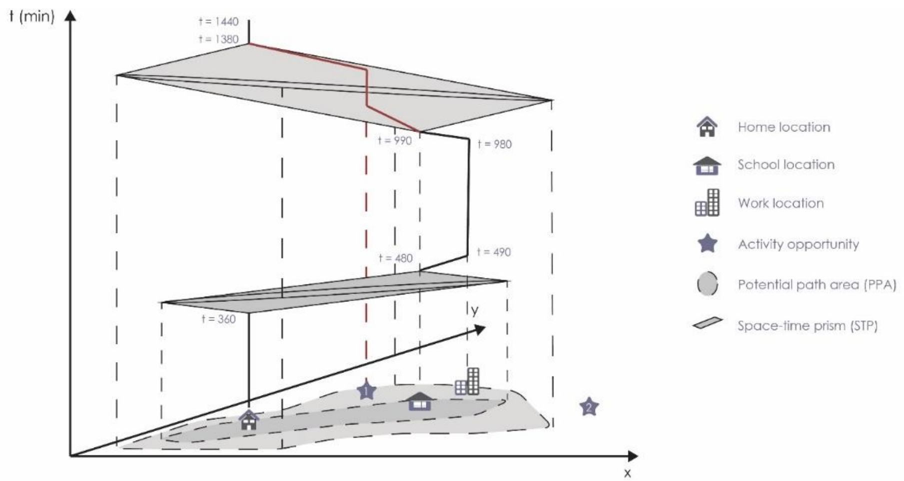

Fig. 27. Space-time prism (STP) and potential path area (PPA) for a participant given certain temporal constraints

The summation of all potential minutes at all accessible locations, determines the accessibility index for one STP, given certain spatial as well as temporal constraints defined by an individual's activity diary. The available time budget was determined for each STP associated to a free time period between two fixed activities:

$$A_{i,j} = \sum_{c \in \{t_{i,c}+t_{c,j} < T_{i,j}\}} N_c(T_{i,j} - (t_{i,c} + t_{c,j})) \quad (1)$$

where *c* is a grid cell centroid, $t_{i,c}$ and $t_{c,j}$ represent the calculated travel time from the location of the previous fixed activity *i* to the grid cell centroid *c* and from the grid cell centroid *c* to the location of the next fixed activity *j* respectively, N_c equals the number of activities at the grid cell *c*, and T_{ij} denotes the available time budget between the two fixed activities. A condition should be fulfilled for each grid cell centroid *c* in order to be included in the summation for the calculation of A_{ij}:

$$t_{i,c} + t_{c,j} < T_{i,j} \quad (2)$$

Eq. (2) indicates that the sum of the time needed to travel from the location of the previous fixed activity *i* to the grid cell centroid *c* and from the grid cell centroid *c* to the location of the next fixed activity *j* has to be less than the available time budget between those two fixed activities. This ensures that only the accessible locations given both the spatial and temporal constraints of the individual are incorporated in the calculation. Herein, no minimum threshold for activity time was defined, as a generalized measure of accessibility to activity locations is measured.

Eventually, an individual's accessibility was determined by the summation of the accessibility score for each STP throughout the day, calculated in Eq. (1):

$$A_{ST} = \sum_{i,j} A_{i,j} \quad (3)$$

The accessibility score A_{ST} represents the total amount of minutes an individual can spend for all available time budgets T_{ij} between consecutive fixed activities *i* and *j*, given his/her spatio-temporal constraints.

5.4.2 Spatial accessibility measure

In order to underline the benefits of applying a spatio-temporal, person-based accessibility measure, the results were compared to a gravity-based metric that only accounts for the home-based, static activity of an individual. In other words, the individual's accessibility to activity opportunities is solely determined by his/her home location. The surveyed travel times extracted from the Utah Statewide Travel Study served as an indication for the actual distribution of the distance impedance to discretionary opportunities. The best fitting function was a 6^{th} order decay, not further described here for the sake of brevity.

This weight function was used to calculate the spatial, gravity-based accessibility score to all grid cell centroids:

$$A_{S,k} = \sum_{c} W_{k,c} N_c \tag{4}$$

where $W_{k,c}$ is the weight associated with a travel time from home location k to grid cell c, and N_c represents the number of activities at the grid cell c.

5.5 Results

The relationship between an individual's accessibility and his/her participation in activities was analyzed with a maximum likelihood estimation of a zero-inflated negative binomial regression model in R.

The zero-inflated negative binomial (ZINB) was selected because of the large number of respondents in the sample without any discretionary trip on the day of travel (n = 2,960). In addition, the negative binomial is preferred because the dependent variable (the number of discretionary activities participated in) is a discrete count and due to overdispersion of the data (variance = 3.3993 and mean = 1.8410 for the dependent variable). In addition to the calculated accessibility index, various socio-demographics were incorporated into the regression model as independent variables to control for variables that have the ability to simultaneously affect activity participation. The control variable for limited mobility was omitted because it was highly correlated with age. The reference categories represented an average population group: middle-aged, White or Caucasian, non-Hispanic male with average income, a household size of three or four persons and a driver's license living in a downtown urban neighborhood. In general, the model fits were assessed using the AIC statistics as well as a comparison to a non-linear LOESS curve (see below). The models obtain similar levels of fit to those found elsewhere in the literature. The model residuals were additionally tested for the presence of spatial autocorrelation using the Moran's I test, and the residuals for all models reported were highly insignificant with p-values ranging from 0.4401 to 0.9513, depending on the model specification.

The results of the model in Table 15 indicate a positive and highly significant (p-value < 0.001) relationship for the spatio-temporal accessibility index for the zero-inflated negative binomial regression model (AIC = 39567.41).

Table 15. Count model coefficients (negbin with log link) for the zero-inflated negative binomial regression of activity participation in relation to the spatio-temporal accessibility

Independent variable		IRR[1]	Std. Err.	Z-value	P-value	
(Intercept)		0.6298	0.0568	-8.1450	0.0000	***
Spatio-temporal accessibility index		1.0356	0.0011	31.3880	0.0000	***
Age (reference "35 - 64")	Under 18	0.9766	0.0603	-0.3930	0.6946	
	18 - 34	0.5725	0.0849	-6.5720	0.0000	***
	65 or older	0.9745	0.1251	-0.2070	0.8363	
Gender (reference "Male")	Female	1.2135	0.0184	10.5360	0.0000	***
Race (reference "White or Caucasian")	African American or Black	0.9567	0.1566	-0.2830	0.7772	
	American Indian or Alaskan Native	1.0248	0.1839	0.1330	0.8940	
	Asian	0.8004	0.0655	-3.3970	0.0007	***
	Other	0.8454	0.0753	-2.2310	0.0257	*
	Prefer not to answer	0.9108	0.0789	-1.1850	0.2360	
Hispanic (reference "No")	Yes	0.8261	0.0568	-3.3630	0.0008	***
	Prefer not to answer	0.8981	0.0950	-1.1320	0.2578	
Driver's license (reference "Yes")	No	0.8355	0.0587	-3.0630	0.0022	**
Income (reference "$35,000 - $74,999")	Under $35,000	0.9264	0.0273	-2.8060	0.0050	**
	$75,000 - $149,999	1.0101	0.0213	0.4690	0.6390	
	$150,000 or more	1.0446	0.0373	1.1710	0.2417	
	Unspecified	0.9308	0.0288	-2.4910	0.0127	*
Household size (reference "3 - 4")	1	1.1663	0.0327	4.7070	0.0000	***
	2	1.0478	0.0213	2.1940	0.0282	*
	5 or more	1.0498	0.0236	2.0610	0.0393	*
Neighborhood type (reference "City, downtown")	Rural	1.1716	0.0625	2.5350	0.0112	*
	Small town	1.1871	0.0532	3.2270	0.0013	**
	Suburban (housing)	1.1469	0.0504	2.7200	0.0065	**
	Suburban (mixed)	1.1196	0.0512	2.2040	0.0275	*
	City, residential neighborhood	1.1523	0.0500	2.8360	0.0046	**
Signif. codes:		'***' 0.001	'**' 0.01	'*' 0.05	'.' 0.1	

[1]*incidence rate ratio*

The strength of association is relatively high, as a 1 unit increase in the spatio-temporal accessibility level (1 million minutes) corresponds to a 3.56% increment in activity participation (Table 15). As a result, a 1 unit standard deviation increase in the spatio-temporal accessibility level (10.57 million minutes) corresponds to a 44.74% increment in activity participation, which provides a more comprehensible and commonly applied unit of measurement. The accessibility score was measured as the sum of all minutes available for participation across all activity locations, giving rise to the large measurement scale (see Fig. 27). The zero-inflation model coefficients for the spatio-temporal accessibility show a negative relationship for zero inflation, which indicates that an increase in accessibility leads to a decrease in probability of not participating in any activities (Table 16).

Furthermore, a strong relationship with participation for most socio-demographics was apparent. Lower ages (18 – 34) are negatively associated to activity participation and participate 42.75% less in discretionary activities. For race, Asian participants have a significantly negative coefficient, indicating a lower participation rate than the other race groups. In addition, Hispanics are negatively associated with activity participation, in relation to non-Hispanics. As mentioned in the literature, driver's license ownership plays an important role in activity participation, as participants who do not own a driver's license have a 16.45% lower participation rate. Similar to the ability to use a car, a higher income is a well-known facilitator for trip generation and activity participation.

The zero-inflated model coefficients support this assumption, as not having a driver's license increases the probability of participating in zero activities. The regression model shows that lower income households (under $35,000) have a 7.36% lower participation rate than households with an average income. An opposing relationship is found for women, who have a 21.35% higher participation rate than men. The household size has an impact on activity participation, as single or dual person households have a significantly higher participation rate than medium households. Interestingly, the spatial variable related to the type of neighborhood revealed that participants living in a rural or suburban neighborhood, a small town or a residential neighborhood have a significantly higher activity participation that urbanites living in the downtown area.

Table 16. Zero-inflation model coefficients (binomial with log link) for the ZINB regression of activity participation in relation to the spatio-temporal accessibility level

Independent variable		IRR[1]	Std. Err.	Z-value	P-value	
(Intercept)		-14.6792	203.0285	-0.0720	0.9424	
Spatio-temporal accessibility index		-0.2592	0.0503	-5.1490	0.0000	***
Age (reference "35 - 64")	Under 18	1.7689	0.8976	1.9710	0.0488	*
	18 - 34	-11.5305	68.8934	-0.1670	0.8671	
	65 or older	1.0450	1.5896	0.6570	0.5109	
Gender (reference "Male")	Female	-0.4564	0.8722	-0.5230	0.6008	
Race (reference "White or Caucasian")	African American or Black	3.2136	1.3194	2.4360	0.0149	*
	American Indian or Alaskan Native	3.0364	1.2533	2.4230	0.0154	*
	Asian	0.6700	1.1787	0.5680	0.5698	
	Other	0.6548	1.6087	0.4070	0.6840	
	Prefer not to answer	2.6899	1.2252	2.1960	0.0281	*
Hispanic (reference "No")	Yes	-3.2633	2.6315	-1.2400	0.2149	
	Prefer not to answer	-0.4654	1.3037	-0.3570	0.7211	
Driver's license (reference "Yes")	No	3.8891	1.1533	3.3720	0.0007	***
Income (reference "$35,000 - $74,999")	Under $35,000	0.8010	0.6961	1.1510	0.2499	
	$75,000 - $149,999	-0.8733	0.9376	-0.9310	0.3516	
	$150,000 or more	1.7189	0.5950	2.8890	0.0039	**
	Unspecified	-9.0996	47.5060	-0.1920	0.8481	
Household size (reference "3 - 4")	1	-0.4701	0.9749	-0.4820	0.6297	
	2	-2.0984	1.2986	-1.6160	0.1061	
	5 or more	0.6619	0.4849	1.3650	0.1722	
Neighborhood type (reference "City, downtown")	Rural	12.3261	203.0390	0.0610	0.9516	
	Small town	11.1761	203.0325	0.0550	0.9561	
	Suburban (housing)	14.1174	203.0291	0.0700	0.9446	
	Suburban (mixed)	14.3915	203.0282	0.0710	0.9435	
	City, residential neighborhood	14.1556	203.0295	0.0700	0.9444	
Signif. codes:		*'***' 0.001*	*'**' 0.01*	*'*' 0.05*	*'.' 0.1*	

[1]*incidence rate ratio*

The negative binomial (NB) and ZINB model fits are compared to the non-parametric local polynomial regression (LOESS) curve of the surveyed participation data, in order to assess the validity of the regression models in predicting activity participation based on the accessibility level. The LOESS modelling method does not require a global function to fit a model to the data and, resultantly, reveal patterns and trends in the data. Instead, it fits segments of the data through a moving window-smoother, which performs a regression for each point, based on the neighboring points and their values. Resultantly, this curve represents the actual distribution of activity participation extracted from the Utah Statewide Travel Survey. Fig. 28 shows that the LOESS curve explains the major concentrations of values at average accessibility levels (participants with some temporal or spatial constraints) and the participants with the highest accessibility levels (mostly participants with no temporal restrictions). In addition, it highlights that the function for the NB and ZINB models both generally fit the LOESS curve well. However, the models fail to capture the diminishing effect on participation for the highest levels of accessibility. According to the prediction models based on the negative binomial and zero-inflated negative binomial regression, participation should increase exponentially when accessibility increases, which is not the case considering realized participation behavior. Interestingly, for both the models and the LOESS fit, the greatest rate of change in participation occurs within the mid-range of accessibility scores. This does not align with the hypothesis commonly outlined in the literature that participation gains should be highest with increases at the low end of the accessibility range (K. Martens, 2016 (in press)). In comparison to the NB, the ZINB succeeds better in capturing the higher increase in participation for the mid-range of accessibility levels, whereas it slightly overestimates the increase for the low-range.

Next, the spatio-temporal accessibility measure is compared to the zone-based measure. The accessibility scores are transformed into Z-scores in order to compare the accessibility-participation relationship across two different types of accessibility measurements. In contrast to the moderate correlation among spatio-temporal accessibility and participation ($r = 0.3771$), the spatial accessibility is actually negatively correlated to participation ($r = -0.0306$). The zero-inflated negative binomial regression model (AIC = 40944.34) with the spatial accessibility as independent variable (along with the various socio-demographic variables) confirms this finding (Table 17).

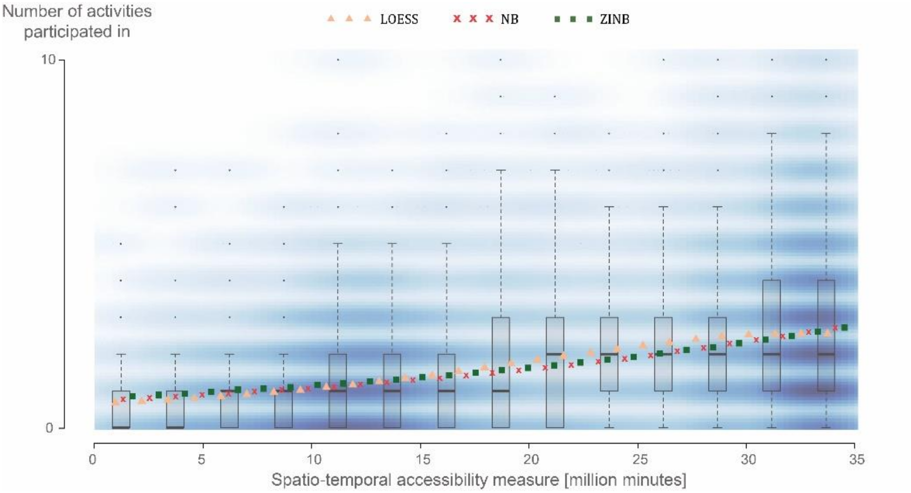

Fig. 28. Correspondence of the negative binomial function to the LOESS curve

Table 17. Count model coefficients (negbin with log link) for the zero-inflated negative binomial regression of activity participation in relation to the spatial accessibility level

Independent variable		IRR[1]	Std. Err.	Z-value	P-value	
(Intercept)		1.6350	0.0292	16.8590	0.0000	***
Spatio-temporal accessibility index		0.9710	0.0094	-3.1400	0.0017	**
Age (reference "35 - 64")	Under 18	0.5858	0.0944	-5.6670	0.0000	***
	18 - 34	0.8352	0.0221	-8.1600	0.0000	***
	65 or older	1.4039	0.0281	12.0900	0.0000	***
Gender (reference "Male")	Female	1.3862	0.0212	15.4000	0.0000	***
Race (reference "White or Caucasian")	African American or Black	1.0225	0.1571	0.1420	0.8873	
	American Indian or Alaskan Native	0.8988	0.1908	-0.5590	0.5759	
	Asian	0.8307	0.0699	-2.6540	0.0079	**
	Other	0.8261	0.0816	-2.3390	0.0193	*
	Prefer not to answer	0.9248	0.0836	-0.9350	0.3498	
Hispanic (reference "No")	Yes	0.8542	0.0628	-2.5090	0.0121	*
	Prefer not to answer	0.8917	0.0994	-1.1540	0.2485	
Driver's license (reference "Yes")	No	0.9081	0.0601	-1.6030	0.1089	
Income (reference "$35,000 - $74,999")	Under $35,000	0.9674	0.0288	-1.1540	0.2486	
	$75,000 - $149,999	0.9631	0.0231	-1.6260	0.1040	

	$150,000 or more	0.9589	0.0392	-1.0710	0.2842	
	Unspecified	0.9194	0.0312	-2.6940	0.0071	**
Household size (reference "3 - 4")	1					
	2	1.0161	0.0369	0.4340	0.6643	
	5 or more	0.9602	0.0249	-1.6320	0.1026	
Neighborhood type (reference "City, downtown")	Rural	1.1453	0.0258	5.2560	0.0000	***
	Small town	1.6350	0.0292	16.8590	0.0000	***
	Suburban (housing)	0.9710	0.0094	-3.1400	0.0017	**
	Suburban (mixed)	0.5858	0.0944	-5.6670	0.0000	***
	City, residential neighborhood	0.8352	0.0221	-8.1600	0.0000	***
Signif. codes:		*'***' 0.001*	*'**' 0.01*	*'*' 0.05*	*'.' 0.1*	

[1]incidence rate ratio

The control variable neighborhood type was omitted because of its high correlation with the index of spatial accessibility. The resulting model indicates a negative and highly significant (p-value < 0.001) relationship between spatial access and the dependent variable of activity participation. The model finds that a 1 SD increase in spatial accessibility is associated with a 2.90% decline in activity participation. This is a much smaller effect size than found for the space-time measure above, which showed a change of 44.74% for a 1 SD change in access. In addition, the zero-inflation model coefficients for the spatial accessibility are not significant (p-value = 0.6233). This brings important ramifications for future research aimed at quantifying the benefits of accessibility, since it appears that spatial measures alone may show insignificant or even counterintuitive relationships.

5.6 Discussion and conclusion

This article has proposed a person-based, spatio-temporal accessibility analysis, based on travel survey data for 11 counties in Utah, to explore the relationship between accessibility and activity participation. In answer to the shortcomings of previous studies that use aggregate, static accessibility measures, this study highlights the benefits of incorporating temporal restrictions into the analysis. To that end, a spatio-temporal accessibility metric was constructed that accounted for an individual's complex time budget throughout the day.

The measure resulted in a personal accessibility level, which expressed the potential number of minutes a person can spend at a certain set of accessible facilities over a 24-hour time period, given his/her fixed activities. A zero-inflated negative binomial (ZINB) regression model was used to assess the impact of the accessibility index on the realized activity participation, while controlling for socio-demographic variables that interact simultaneously. The model showed that there is a highly significant, moderate correlation among an individual's spatio-temporal accessibility and his/her actual partaking in activities. Comparison of the negative binomial (NB) and ZINB regression model fits to a locally weighted regression smoother indicated that the models fit the actual distribution well. However, the models fail to grasp the diminishing participation for individuals with high accessibility levels. Additionally, various socio-demographics were significantly related to participation. The spatio-temporal accessibility analysis was compared to a home-based spatial measure, in order to determine the benefits of incorporating temporal and personal constraints into the analysis. A weak, negative correlation was found for the spatial measure, which goes against the theoretic claims on the accessibility-participation relationship. This, however, confirms the need for an accessibility measure that applies time-use concepts and incorporates the fixed temporal constraints people face on a daily basis (e.g., work, picking up or dropping off kids at school, etc.).

Although this paper represents a significant enhancement over prior studies in this domain, there are some limitations that should be addressed in future research. First, the interpretation of the resulting accessibility index does not differentiate between opportunity types. In the analysis, a participant's accessibility is based on the time he/she can spend at all activity locations accessible for that person. However, the type of activity plays an important role in the quality of the activity opportunity. On the one hand, there could be interesting differences in accessibility for various activity types. On the other hand, the duration of the activity varies for different activity types, making some activities more attractive for short stops, while other activities have a longer duration. It is commonplace in detailed studies of accessibility to particular types of activity locations to provide minimum and maximum thresholds on what constitutes an appropriate opportunity to participate (e.g., lower thresholds for shopping or higher thresholds for recreation (Cross, 1998)). Because the proposed study aggregates over all possible types of activities, no threshold for either minimum or maximum activity times was used. Future work could focus on isolating a particular destination type, and a particular participation type or on incorporating minimum or maximum activity participation times for each activity type into the proposed equations. In addition, detailed Sequence Alignment Methods (SAM) can be used to group behavioral patterns and represent daily activity patterns based on the Utah Statewide Travel Survey (Wilson, 1998). However, given the infrequency with which particular activities are participated, a more focused analysis would require a longer time-horizon in data collection, or rely on stated behaviors rather than revealed travel behavior. In addition, more detailed survey information on in-home activities could provide insights on the role of information and communication technologies on the substitution and complementarity for out-of-home activities (Mokhtarian, 2009). In addition, the application of more detailed spatiotemporal accessibility measures such as the time geographic density estimation proposed by Horner and Downs (2014) might provide additional benefits in assessing person-based accessibility measures' relation to activity participation.

Second, the Utah Statewide Travel Study collects survey data for a 24-hour period. Notwithstanding, travel behavior is not only influenced by the time of the day, also larger temporal fluctuations over the week (e.g., playing sports one day in the week) or even the year (more out-of-home activities in the summer due to the weather) can play a key role in activity choice and travel scheduling (Axhausen et al., 2002). Therefore, the analysis does not necessarily represent a typical daily travel behavior for each individual. Although the survey did enquire if travel on the chosen day could be defined as typical, people are most likely to answer this question in reference to whether or not they went to work or other mandatory and regular activities, but participation in discretionary activities is likely a rarer event not considered when answering about one's typical day. Calculating and comparing PPAs for different days could provide valuable insights in variations over various time periods. A multi-week analysis for Zurich, Switserland, by Spissu et al. (2009), for example, showed a high prevalence of intra-personal variability in discretionary activity participation, therefore, underlining the importance of analysis over a longer time period.

Third, as mentioned in the Study Area and Data section, participants with one or more travel activities during the time period from 11 pm to 6 am were not incorporated in the analysis to limit complexity. This enabled to assume a fixed time period for each participant, accounting for the mandatory activity of sleep at the home location. However, some points of interest lend for activities after 11 pm or before 6 am (e.g., bars, movie theaters, etc.). In addition, individuals working in evening, night or morning shifts are left out of the analysis, despite these populations being of special concern, especially if they relate to the growing class of the working poor.

Finally, frequency of participation in discretionary activities is taken as the dependent variable in the analysis presented in this paper. The authors recognize that alternative specifications that model activity duration also appear in the literature (Hsu & Hsieh, 2004; Kim & Kwan, 2003). We are not aware of any compelling theory or empirical evidence to guide our choice between these options, and think that repeating the analysis within the continuous outcome space will be valuable in continuing research. As a result, the paper provides a basis for further exploration of the key role an individual's temporal constraints play in explaining the relationship between accessibility and activity participation. Future research should focus on the nuances of this relationship's impact on different segments of the population and the interaction with other socio-demographic variables, in order to further investigate the extent to which accessibility could lead to various types of social in- or exclusion.

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Chapter 6: Predicting long-term unemployment in Flanders and Brussels

But I work to make a living and I work without a break,
And I work when I am sleeping and I work when I'm awake.
I'd like to leave the city but I can't afford to move,
And I think I'm going under with them way down lowdown smokey factory blues.

Johnny Cash in Smokey Factory Blues, 1975

This chapter is adopted from the following journal article:
Fransen, K., Boussouw, K., Deruyter, G., De Maeyer, P. (Under Review). The relationship between transport disadvantage and employability: predicting long-term unemployment based on job seekers' access to suitable job openings in Flanders, Belgium, *Transportation Research Part A: Policy and Practice*.

Abstract

In no research domain has the application of accessibility been so vital as in the area of linking disadvantaged individuals to job opportunities. The inability to reach locations of employment and, therefore, partake in paid labor is considered to have severe consequences on an individual's economic security and quality of life as well as society's general level of welfare. Unfortunately, existing studies on job accessibility primarily apply aggregate measures that aim to link the population group of active, employed workers to pre-existing job locations. As a result, they fail to capture the person-specific labor-market opportunities for those individuals who are actually unemployed as well as the degree to which accessibility to opportunities is related to actual employment rates. The proposed paper answers this limitation by constructing a predictive model for long-term unemployment for job seekers in Flanders, Belgium, dependent on their access by private and public transport to job openings that correspond to their individual preferences and competences. In addition to accessibility, the predictive capacity was determined for various socio-demographics such as age, gender, migration background, educational background and preferred job type. The proposed regression model shows that job accessibility is negatively related to long-term unemployment. In addition, various inequities in long-term unemployment exist for the selected case study. Especially job seekers with a migration background and with higher age (55 years or older) have significantly higher probabilities of remaining unemployed. A conditional inference regression tree indicates that the most disadvantaged groups have a two to three times higher probability of being long-term unemployed. Moreover, higher accessibility levels prove to only benefit those who already are in a more advantaged position. These findings have important ramifications for policies focusing on improving employment rates, as they allow to specifically address those areas of research where major gains can be made.

Keywords: unemployment; job accessibility; social equity; transport disadvantage

6.1 Introduction

Worldwide, employment is considered an indispensable component of everyday life and continues to draw substantial interdisciplinary attention in research and policy. Generally, the inability to reach and, therefore, partake in paid labor is considered to have severe consequences on an individual's economic security and quality of life as well as society's general level of welfare (Andrews & Withey, 2012; Clark, 2005; Shen & Sanchez, 2005). Concomitantly, the Social Exclusion Unit (2003) study on transport and social exclusion pinpoints unemployment as one of the main drivers of transport disadvantage. This highlights the relationship between employment and transportation, and the degree to which the underperformance of one of both elements can reinforce the weaknesses of the other. When this problem is reduced to its transport-geographic essence, accessibility can be defined as a combination of spatial proximity and speed. The closer one lives with respect to a range of possible destinations, the better accessible these are. But also: the faster one is able to move, the larger is his or her radius of interaction, and thus the better the access to potential destinations. In the context of access to the labor market, spatial proximity can be conceptualized as the extent to which the jobseeker's home is spatially embedded in the labor market, while speed can be viewed as the extent to which the jobseeker has access to relatively quick ways to travel to available jobs. In addition, an accurate representation of job accessibility can provide insights in various interdependent mechanisms, such as multimodal job accessibility (Grengs, 2010; Ma & Jan-Knaap, 2014), employability (Matas et al., 2010; McQuaid & Lindsay, 2005), commuting patterns and related job-housing balances (Horner, 2008; Owen & Levinson, 2015) or the so-called 'spatial mismatch' hypothesis (Gobillon et al., 2007; Östh, 2011). As a result, the concept of employment – and more specific, job accessibility as an indicator for employment – has been studied in a wide range of disciplines, such as urban geography, planning and transportation (Cheng & Bertolini, 2013).

Akin to the importance in academic research, (un)employment is deemed an inherent aspect of decision making in various policy domains. The Eurostat (2016) report on the European Union employment statistics considers the proportion of the working age population in unemployment as a key social indicator to study developments in labor markets. In 2015, the unemployment rate for Belgium was 8.5%, which was 0.9% lower than the EU-28 average rate of 9.4%, ranking the country 14^{th} out of 28 European Union member states. However, 4.4% of the active population in 2015 was long-term unemployed, ranking Belgium only 17th out of the EU-28 countries. Herein, unemployment rates represent unemployed persons aged 15 to 74 as a percentage of the labor force, which is the total number of people employed and unemployed. Additionally, a number of spatial as well as social discrepancies can be noted, which indicate that the level of employment is distributed inequitably for the various population groups. In 2016, the unemployment rate for the region of Flanders was 4.9%, whereas the Brussels Capital Region (BCR) scored 16.9%. Moreover, the report shows considerable differences by sex, age and educational level for individuals aged 20-64. The educational level, for example, proves to have a strong impact, as the unemployment rate is only 2.9% or 8.5% for the higher educated living in Flanders or the BCR, respectively, in comparison to 9.7% or 30.7% for the lower educated labor force. In terms of gender, the employment rate is not distributed equitably as men show a 0.3% and 1.5% higher unemployment rate than women in Flanders and the BCR, respectively (Statistics Belgium, 2016). The 2020 objective for Belgium is to counter unemployment and increase the employment rate from 67.6% in 2010 to 73.2% (European Commission, 2010) – a goal far from realistic considering the past years' evolution. This objective is related to the overarching strategy to reduce the number of poor and socially excluded individuals in Europe by 20 million and in Belgium by 380,000 (Ajwad et al., 2013; Marlier & Natali, 2010). Herein, the concept of accessibility plays a major role, as better matching economic opportunities with individuals seeking employment is regarded as an important aspect of labor, housing and antipoverty policies. In the densely populated region of Flanders, for example, 67% of the surveyed unemployed population attribute the inability to find a suitable job to transport-related issues of not being able to reach that particular job opportunity.

For this paper, job accessibility was calculated at an individual level by defining job seekers' access by private and public transport modes to job openings that correspond to their individual preferences and skills. The authors propose a predictive model that examines the relationship between an unemployed job seeker's accessibility to suitable job opportunities and long-term unemployment. Herein, the predictive capacity was additionally determined for various socio-demographics such as age, gender, migration background, educational background and preferred job type. Following this introduction, the paper continues with a brief background on the existing research on job accessibility and employment analysis, and on how present studies generally fail to incorporate individual, person-based factors related to both supply and demand.

6.2 Background

In no research domain has the application of accessibility been so vital as in the area of linking disadvantaged individuals to job opportunities (Kwan et al., 2003; Scott, 2000). Commonly, poor accessibility to employment opportunities is attributed to two main reasons. Aspects of spatial mismatch between the residences of those in need of a job and the location of job opportunities impact an individual's access to employment. This mismatch is even more apparent for low-skilled workers seeking low-skilled jobs. Korsu and Wenglenski (2010), for example, examine the relationship between job accessibility, neighborhood poverty levels and the risk of long-term unemployment for workers living in the Paris Region and conclude that low-skilled workers have a higher risk of long-term unemployment when faced with low accessibility levels and exposure to high-poverty neighborhoods. Job accessibility was initially studied as a possible causal factor for urban poverty, as low-skilled jobs are often beyond the reach of public transportation (Hess, 2005). As a result, individuals without a privately owned vehicle face a considerable obstacle in accessing job opportunities, which may further confine existing societal inequities (Kawabata, 2003a). Therefore, car ownership additionally affects the degree to which one has access to job opportunities. A large number of studies aim to identify the various levels of interplay between access to jobs, employment and a wide range of socio-demographics such as car ownership, but also gender, age or income (Cervero et al., 2002; Gao et al., 2008; Matas et al., 2009).

There are many ways to interpret and calculate job accessibility. Based on Hansen's definition of accessibility as 'the potential of opportunities for interaction' (Hansen, 1959), job accessibility can basically be divided into three components: the opportunities for interaction or, specifically, the work locations; those seeking interaction, in this case the workers; and the means by which the potential for interaction is measured, namely through the transport system. Most studies apply this framework to identify the degree to which the transport system – be it private or public – connects workers to potential work locations. Generally, this is measured by an aggregate, potential-based approach that calculates the number of job opportunities at a destination zone within a certain travel cost from the origin zone. However, bearing in mind concepts of transport equity and social exclusion, a more solid and detailed interpretation of the job accessibility framework is desired. The group of active, employed workers primarily focused on in studies on job accessibility is not an accurate representation of individuals who are strongly disadvantaged. In answer to this shortcoming, studies frequently define welfare recipients as the group of interest for accessibility analysis (Gurley & Bruce, 2005; Ong, 1996). However, using the actual job seekers also incorporates aspects of willingness to partake in an employment activity. Kawabata (2003b), for example, calculates multimodal accessibility levels for job seekers aggregated at the traffic analysis zone level for the cities of Boston, San Francisco and Los Angeles. Similarly, the existing literature commonly examines accessibility to pre-existing job locations or job opportunities that are already occupied. Although these job locations provide an indication of possible higher concentrations of opportunities, they fail to capture the actual distribution of opportunities for those individuals in the disadvantaged position of unemployment. In a study on the spatial variation in job accessibility in the Boston Metropolitan Area, Shen (2001) advocates the importance of examining job openings: on the one hand, they provide a more suitable indicator in light of antipoverty policy and welfare reform whereas, on the other hand, new jobs are spatially more dispersed than pre-existing jobs. Recent research about suburbanization processes of the labor market in the Brussels Metropolitan Area show similar findings; jobs for the lower skilled appear to systematically move out of the urban core, which reduces access to jobs among the already often deprived population that is living centrally in the city (Sansen et al., forthcoming).

The scarce body of literature taking into account job seekers and their access to job openings mainly applies aggregate accessibility measures that do not consider job matching specifications at the individual level (e.g., Kawabata (2003b), Shen (2001) and (Fransen et al., forthcoming)). This leads to an overestimation of both the accessible job opportunities and the level of job competition, as the opportunity is only available in reality when it matches the job seeker's preferences and vice versa. Moreover, aspects related to the job specificity are proven to strongly impact the level of satisfaction related to job participation (Drobnič et al., 2010; Van de Werfhorst, 2002). Blumenberg and Ong (1998), for example, indicate that the distribution of expected wage offers is more advantageous if jobs match the skills and expertise of potential job seekers. Despite the presence of studies that focus on job matching of unemployed job seekers to vacancies, the existing studies do not recognize accessibility as a determining factor in job matching (Calvó-Armengol & Zenou, 2005; Smith & Zenou, 2003). Drigas et al. (2004), for example, use a corporate database of unemployed and enterprise profile data to measure the unemployment suitability for a certain job based on historical data on approved and rejected cases for job seekers in the same social class.

6.3 Study area and data

The study area consists of Flanders, which is the northern, Dutch-speaking part of Belgium. The region is densely populated and is characterized by a historically polycentric urban system that has entailed vast sprawling development in the post-war period. As a result, the distribution of job seekers is concentrated around and in between the major cities in the center of the region, highlighting the delineation of the urban and economic network of the so-called 'Flemish Diamond'. The Diamond is of crucial economic importance for the immediate environment (100-150 km) as well as for the European and global economy (Vanhaverbeke, 1998). Job locations are mainly centralized in the larger urban areas with high concentrations in the center and the west of the region (Fig. 29). The density map is derived from the magnitude-per-unit area from the points within a neighborhood around each cell. However, the central labor market core, which roughly covers the axis Antwerp-Brussels, supplies the majority of specialized jobs, whereas the rest of Flanders is characterized by higher concentrations of generic and industrial jobs (van Meeteren et al., 2016). This indicates a spatial mismatch between job locations and job seekers for suburban and especially rural areas leading to long distance and time consuming commutes from these areas to city centers with high concentrations of job opportunities. It is crucial to stress the importance of the Brussels labor market for Flemish employees and employment seekers. Although Brussels is a separate administrative region in the Belgian federation, more than 10% of all Flemish working residents are employed in Brussels. Being a city region, Brussels shows a high job-housing ratio, which is not present in a large part of suburban Flanders. Also, Brussels houses an important concentration of highly specialized services, including national and European government agencies, banks, and headquarters. In recent decades, the mismatch between skills required by employers and present job seekers' profiles is considered to be one of the primary causal factors for various mobility and societal equity issues.

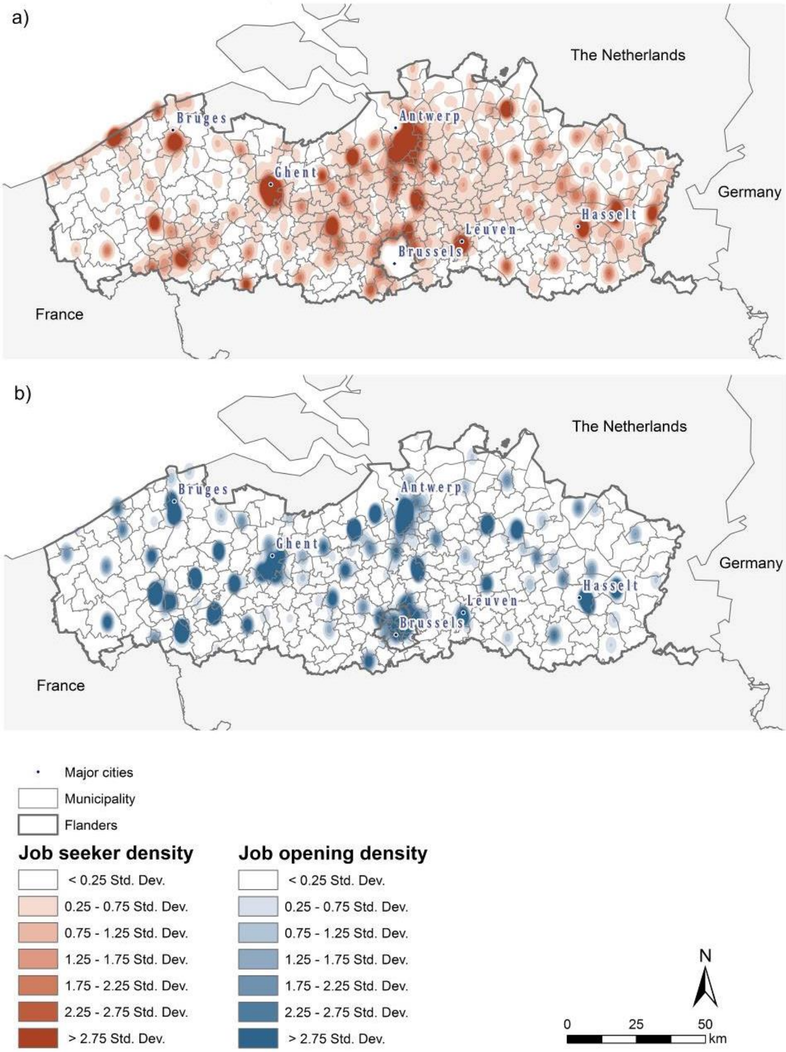

Fig. 29. a) Job seeker density in Flanders and b) job opening density in Flanders and Brussels in 2015, the density map is derived from the magnitude-per-unit area from the points within a neighborhood around each cell.

The public employment agency provided the data on 746,717 job openings for Flanders and the BCR at the address level. The job openings for the BCR were added because of the sizeable number of employees residing in Flanders and working in Brussels.

Table 18 shows that the largest part of the job openings are in the domains of retail & ICT and industry and more than half of the jobs are considered as “bottleneck professions” - jobs that are difficult to fill due to the lack of sufficient qualified candidates. The available data contains the level of education of all job seekers, as well as the official diplomas or training qualifications requested by the advertised job openings, whereas the type of offered employment was provided on the level of the specific profession. This is the most specific level of detail consisting of 675 different profession types aggregated in 6 job domains, which are listed in Table 19 and Table 18.

Table 18. Characteristics for the job openings in Flanders and Brussels, 2015

Job opening characteristic		Number	Percentage
Required driver's license	*No requirement*	590,116	79.03%
	A (scooter or motor bike)	1,324	0.18%
	B (car)	138,423	18.54%
	C (truck)	15,965	2.14%
	D (bus)	812	0.11%
	G (agricultural vehicle)	70	0.01%
Educational level	*Primary + first level secondary (low)*	13,787	1.85%
	Second level secondary (low)	35,087	4.70%
	Third and fourth level secondary (low)	221,186	29.62%
	Apprenticeship (low)	2,060	0.28%
	Partial professional secondary (medium)	931	0.12%
	Higher professional (medium)	6,596	0.88%
	Bachelor (high)	142,142	19.04%
	Master (high)	45,263	6.06%
	Not specified	279,658	37.45%
Job domain	*Construction*	70,469	9.44%
	Retail and ICT	229,651	30.75%
	Services	83,256	11.15%
	Industry	209,029	27.99%
	Transport and logistics	84,821	11.36%
	Education and Health Care	36,828	4.93%
	No requirements	32,663	4.37%
Bottleneck profession	*Yes*	390,835	52.34%
	No	355,882	47.66%

Both datasets are limited to the Dutch-speaking population, including only job openings targeted towards job seekers that speak Dutch at least, meaning that potential matches for non-Dutch speaking job seekers might be underestimated. This is an important caveat, since many recently arrived immigrants, but also suburbanizing former residents of Brussels only speak English or French, which does not necessarily prevent them from taking up a position with a Flemish employer.

Table 19. Socio-demographics for the job seeker population in Flanders, 2015

Socio-demographics		Job seekers	Percentage
Gender	*Female*	226,312	47.03%
	Male	254,938	52.97%
Age	*17 or younger*	3,227	0.67%
	18 - 24	128,391	26.68%
	25 - 34	133,486	27.74%
	35 - 54	163,809	34.04%
	55 or older	52,337	10.88%
Immigrant	*No*	369,127	76.70%
	Yes	112,123	23.30%
Driver's license	*No*	164,077	34.09%
	A (scooter or motor bike)	6,474	1.35%
	B (car)	291,330	60.54%
	C (truck)	14,043	2.92%
	D (bus)	4,063	0.84%
	G (agricultural vehicle)	1,263	0.26%
Education	*Primary + first level secondary (low)*	84,422	17.54%
	Second level secondary (low)	88,120	18.31%
	Partial professional secondary (low)	8,909	1.85%
	Apprenticeship (low)	9,228	1.92%
	Third and fourth level secondary (medium	184,019	38.24%
	Higher professional (medium)	5,691	1.18%
	Bachelor (high)	59,052	12.27%
	Master (high)	41,809	8.69%
Preferred job domain	*Construction*	35,012	7.28%
	Education and Health Care	47,899	9.95%
	Industry	106,142	22.06%
	Retail and ICT	135,983	28.26%
	Services	104,003	21.61%
	Transport and logistics	49,003	10.18%
Population density (inh/ha)	*Very low (<6)*	94,060	19.54%
	Low (6-15)	110,421	22.94%
	Average (15-25)	84,021	17.46%
	High (25-40)	61,427	12.76%
	Very high (>40)	131,321	27.29%
Unemployment duration	< 1 year	328,784	68.32%
	> 1 year	152,466	31.68%

Data for job seekers residing in Flanders was provided at the address level by the Flemish Employment and Vocational Training Agency (*Vlaamse Dienst voor Arbeidsbemiddeling en Beroepsopleiding* or VDAB). Due to privacy issues, the data was aggregated at the road intersection level by connecting each job seeker to the closest intersection. This elaborate dataset contains information on socio-demographics (e.g., gender, age and immigration status), skills (e.g., driver's license ownership and educational level) and job preferences for

481,250 individuals registered as job seekers in Flanders in 2015. Herein, job seekers are considered to have a migration background if their current or previous nationality is non-EU. The different population segments were well represented, yet the majority of the job seekers were low- or medium-educated and a relatively large part did not own a driver's license (Table 19). Low education coincides with levels 0-2, medium education with levels 3-4 and high education with levels 5-8 of the International Standard Classification of Education (UNESCO Institute for Statistics, 2011). In addition, more than 30% of the job seekers remained unemployed after one year of actively seeking a job.

6.4 Methodology

The following calculation method was applied in order to delineate the number of suitable job opportunities for each individual job seeker with respect to possible competition by job seekers with a similar profile. Herein, suitable job openings were matched to the job seekers based on four preconditions:

- The job seekers' educational or training qualifications correspond to the educational level requested by the job opening. If no educational level was requested, this precondition was automatically met irrespective of the job seeker's qualifications.
- One of the job seekers' preferred profession types matches the profession as advertised in the job opening. Each job seeker has the ability to provide up to eight different profession preferences.
- The job seeker owns a driver's license in accordance to the job opening's required driver's license type, which means that job seekers without a driver's license will only be matched with job opening that do not request the possession of it. For job seeker's with a driver's license, however, jobs without driver's license specifications were considered suitable.
- Starting from the road intersection nearest to the job seeker's home address, the job opening is accessible by private motorized vehicle or public transport within a predefined cut-off time. A distance decay was applied to account higher weights to jobs that are closer to the job seeker's residence.

First, the travel cost for each job seeker to all potentially accessible job opening locations was determined by constructing an origin-destination cost matrix (ODCM) for both private motorized vehicles and for public transport. This travel cost was calculated for an average Tuesday at 5 PM, and, consequently, simulates the impedance for the work-to-home commute. The analysis was performed separately for both transport modes and each month in 2015, resulting in 24 ODCMs. Due to the high level of detail and, therefore, calculation complexity, the duration for calculating one ODCM varied from 51 to 53 hours. In consultation with the public employment agency, a maximum travel time of 90 minutes was appointed. For the public transport analysis, this includes in- and egress times through the pedestrian network, waiting times, (dis)mounting times and timetable-based times through the transit network General Transit Feed Specification files (GTFS). The GTFS for bus, tram, metro and rail for Flanders and Brussels are freely available through iRail (Tiete & Colpaert, 2016). The network for private motorized vehicles applies historical speed data provided by TomTom to account for congestion times. Second, a competition factor was calculated for each job seeker based on the distribution of all other job seekers with a similar profile who might apply for an analogous job opening:

$$C_s = \sum_{\substack{i \in \{t_{si} < 90, \\ E_i = E_s, \\ P_i \in P_s\}}} W(t_{si,m=f(D_i)}) \tag{1}$$

where C_s is the competition factor for each job seeker *s*, E_i and E_s are the educational level attained by possible competitor *i* and job seeker *s*, respectively, P_i and P_s are the sets of profession type preferences pursued by possible competitor *i* and job seeker *s*, respectively, and $W(t_{si,m})$ is a stepwise approximation of the negative exponential weighting function based on a mathematical travel time t_{si} by transport mode *m* from job seeker *s* to possible job competitor *i*. The transport mode *m* for travel time t_{si} is dependent on each competing job seeker's driver's license ownership D_i: if the job seeker has a driver's license, the travel mode that provides the most optimized choice set was considered the preferred travel mode, whereas a job seeker without a driver's license was solely limited to public transport. The best fitting weight function was estimated with the actual travel times reported in the Flemish Research on Travel Behavior survey (*Onderzoek Verplaatsingsgedrag Vlaanderen* surveyed in 2008-2013), which represent the distribution of the distance impedance for commutes in the region of Flanders for both private motorized transport and public transport. The weight functions are equal to 1 for travel times under the threshold of 10 minutes and decrease stepwise every 10 minutes according to the corresponding exponential. Third, the number of matching opportunities was summarized for each job seeker:

$$O_{s,T} = \sum_{\substack{o \in \{t_{so} < 90, \\ E_o = E_s, \\ P_o \in P_s, \\ D_o = D_s\}}} W(t_{so,m=f(D_s)}) N_{T,o} \tag{2}$$

where $O_{s,T}$ is the accessible number of job opportunities for job seeker s during the month T, E_o and E_s are the educational level required for the job opening o and attained by the job seeker s, respectively, P_o is the profession type proposed by the job opening o and P_s is the set of profession type preferences pursued by the job seeker s, respectively, D_o and D_s are the driver's license type necessary for the job opening o and acquired by the job seeker s, respectively, $W(t_{so,m})$ is a stepwise approximation of the negative exponential weighting function based on a mathematical travel time t_{so} by transport mode m from the job seeker s to job opening o, and $N_{T,o}$ is the number of vacancies for job opening o during the month T. The travel mode m for travel time $t_{s,o}$ is dependent on the job seeker's driver's license ownership D_s, again maximizing each person's choice set based on the most beneficial travel mode considering the person's driver's license ownership. Finally, these job opportunities were weighted by the number of job seekers with a similar profile and summarized for each month to determine each job seeker's weighted access to job opportunities over a one year period:

$$A_s = \sum_{T=1}^{12} \frac{O_{s,T}}{C_s} \tag{3}$$

where A_s is the individual accessibility score per job seeker s, T is the month, $O_{s,T}$ is the accessible number of job opportunities for job seeker s during month T, and C_s is the competition factor for each job seeker s.

6.5 Results

A point density map was constructed to delineate the spatial distribution of the accessibility to suitable jobs for all job seekers in the study area. Fig. 30 shows that the highest concentrations of job accessibility are found around the cities of Ghent, Antwerp, Brussels and Leuven – and primarily for the corridor Antwerp-Mechelen-Brussels – in the center of Flanders, around Hasselt in the east and around Bruges, Bredene, Roeselare and Kortrijk in the west. This aggregate density map, however, provides a general view of areas with a higher and lower job accessibility, whereas it fails to address individual characteristics and possible disadvantages on a person-specific level. In answer to this limitation, the paper continues with a statistical analysis on the individual level to define the relationship between job accessibility and long-term unemployment for various segments of the population.

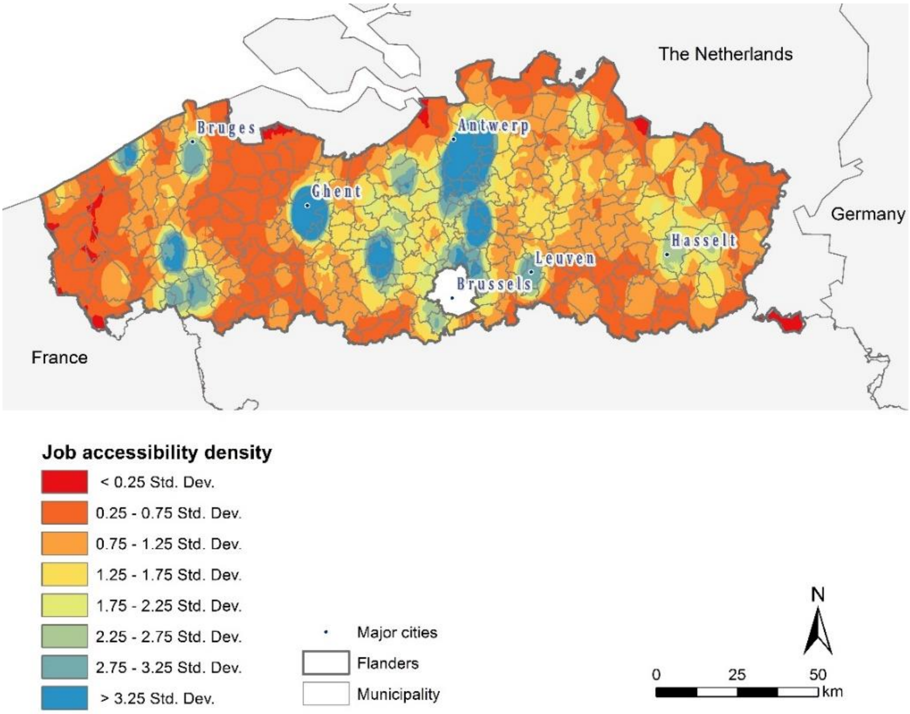

Fig. 30. Job accessibility density based on the weighted number of accessible employment opportunities A_s for all job seekers in the study area of Flanders

First, the Goodman-Kruskal tau index was calculated to test for the strength and direction of the association between independent variables to be used in the regression model. This index is a asymmetric association measure for two-way contingency tables and, therefore, measures the extent to which variation in one variable can be explained by the other and vice versa. Because the tested variables need to be categorical, the job accessibility variable was transformed to a categorical variable with categories 'very low', 'low', 'high' and 'very high'. The tau index shows no significant correlations, except for a low unidirectional correlation between job domain and gender ($\tau_{xy} = 0.237$) and a low to moderate bidirectional correlation between job accessibility and driver's license ownership ($\tau_{xy} = 0.332$ and $\tau_{yx} = 0.111$). Resultantly, driver's license ownership was not incorporated in the regression model.

For the predictive model, a stratified random sample dataset of 70% of the job seekers was constructed to be applied as train dataset. This probability sampling technique ensures that the strata are formed based on the distribution of the characteristics in the entire dataset. The train dataset is used to construct the model that predicts the level of job opportunities based on various socio-demographics, preferences and competences for the remaining 30% of the observations that serve as test data. Due to the logical nature of the dependent variable, a logistic regression model was selected with long-term unemployment (> 1 year unemployed) as dependent variable and the weighted number of accessible opportunities, gender, migration status, age, preferred job domain, educational level and population density of the living environment as independent variables. The reference categories represent an average population group: male, middle-aged (35 – 54), without migration background, living in a neighborhood with average population density, having a bachelor's degree and preferring a job in the domain of business support, retail and ICT.

Table 20 shows that job accessibility is negatively related to the probability of being long-term unemployed. The relationship is relatively weak, as the incidence rate ratio (IRR) indicates that access to one more weighted job opportunity leads to a 3.74% higher probability of finding a job within one year. In addition, the table reveals significant relationships for all control variables except for gender. Job seekers with a migration background are strongly disadvantaged, as they have a 42.23% higher probability of long-term unemployment in comparison to the reference group.

Table 20. Logistic regression model of long-term unemployment in relation to the weighted number of accessible job opportunities and job seekers' socio-demographics, preferences and competences

Independent variable	Estimate	Std. Err.	Z-value	P-value		IRR[1]
(Intercept)	-0.9534	0.0186	-51.27	0.0000	***	
Job accessibility	-0.0381	0.0050	-7.68	0.0000	***	0.9626
Gender (reference "Male")						
Female	-0.0046	0.0091	-0.50	0.6175		NA
Migration background (reference "No")						
Yes	0.3523	0.0098	36.07	0.0000	***	1.4223
Age (reference "35 - 54")						
Under 18	-0.1762	0.0463	-3.81	0.0001	***	0.8384
18 - 24	-1.1522	0.0115	-99.92	0.0000	***	0.3160
25 - 34	-0.5998	0.0100	-60.02	0.0000	***	0.5489
55 or older	0.6607	0.0125	52.76	0.0000	***	1.9361
Preferred job type (reference "Business support, retail and ICT")						
Unspecified	-0.1697	0.0532	-3.19	0.0014	**	0.8439
Construction	-0.2030	0.0178	-11.39	0.0000	***	0.8163
Education and health care	-0.3454	0.0167	-20.66	0.0000	***	0.7079
Industry	-0.1181	0.0120	-9.83	0.0000	***	0.8886
Services	-0.0548	0.0116	-4.72	0.0000	***	0.9467
Transport and logistics	-0.1906	0.0155	-12.29	0.0000	***	0.8265
Education (reference "Bachelor")						
Primary + first level secondary	0.5811	0.0164	35.41	0.0000	***	1.7880
Second level secondary	0.6247	0.0161	38.90	0.0000	***	1.8676
Partial professional secondary	0.9003	0.0314	28.67	0.0000	***	2.4603
Apprenticeship	0.4029	0.0314	12.84	0.0000	***	1.4962
Third and fourth level secondary	0.3174	0.0146	21.77	0.0000	***	1.3736
Higher professional	0.3014	0.0402	7.50	0.0000	***	1.3517
Master	0.0372	0.0194	1.92	0.0550	.	1.0379
Population density (reference "Medium")						
Very low	-0.0505	0.0135	-3.75	0.0002	***	0.9507
Low	-0.0256	0.0129	-1.99	0.0469	*	0.9748
High	0.0766	0.0146	5.24	0.0000	***	1.0796
Very high	0.2508	0.0122	20.53	0.0000	***	1.2850

*Signif. codes: 0.001 '***' 0.01 '**' 0.05 '*' 0.1 '.'*

[1] *incidence rate ratio*

A similar inequity is noted for the various age groups, as job seekers aged 35 or older have a higher chance of long-term unemployment than younger job seekers. Especially job seekers in the highest age group of 55 or older have difficulties finding a job (IRR = 1.9361). The regression model additionally shows that the reference job type of 'Business support, retail and ICT' has the highest probability of long-term unemployment, whereas the education level of 'Bachelor degree' provides job seekers with the lowest probability. Probabilities are notably higher for medium and, especially, lower educated job seekers (approximately 35 – 50% and 80 – 150%, respectively). The probabilities for lower and higher population densities of the neighborhood of residence provide interesting results, as high density neighborhoods are positively related with long-term unemployment, despite the expected higher concentrations of jobs in urban areas.

Next, the predictive capacity of the logistic regression model was assessed by cross validating the actual values provided by the test dataset with the predicted values from the regression model. The mean squared difference between the observed and predicted values indicated a predictive accuracy of 70.43%, which shows a strong yet not fully flawless predictive capacity of the proposed model. In addition to the overall predictive capacity, the area under receiver operating characteristics (AUROC) is a typical performance measurements for binary classifiers that uses the hit rate or the proportions of data points that are correctly considered as positive as a function of the fall-out or probability of the false-positive rate to indicate each variable's predictive power separately. Herein, an AUC value of 1 corresponds to a perfect predictive capacity, whereas a value of 0.5 represents the value for a random predictor. Based on the prediction values for the logistic regression model, the variable of age can be considered as the strongest predictor in selecting job seekers in risk of long-term unemployment (AUROC = 08989). In addition, migration background has a fair predictive capacity (AUROC = 0.7150), whereas the other variables have a low diagnostic accuracy (Table 21).

Table 21. Area Under the Receiver Operating Characteristics as a measure for the diagnostic capacity of each independent model variable separately

	Gender	Migration background	Age	Preferred job type	Education	Population density
AUROC	0.5246	0.7150	0.8989	0.6003	0.6782	0.5907

Finally, the two variables with the highest predictive power were chosen in addition to job accessibility for recursive binary partitioning in a regression tree. Herein, the significant covariates are selected by measuring the association between the dependent variable of long-term unemployment and the covariates measured at different scales. The resulting conditional inference tree highlights each significant combination of the chosen variables, and the predicted probability for long-term unemployment for those population groups. Similar to the logistics regression model, the conditional inference tree shows the inequities that exist among various age groups and job seekers with or without migration background (Fig. 31).

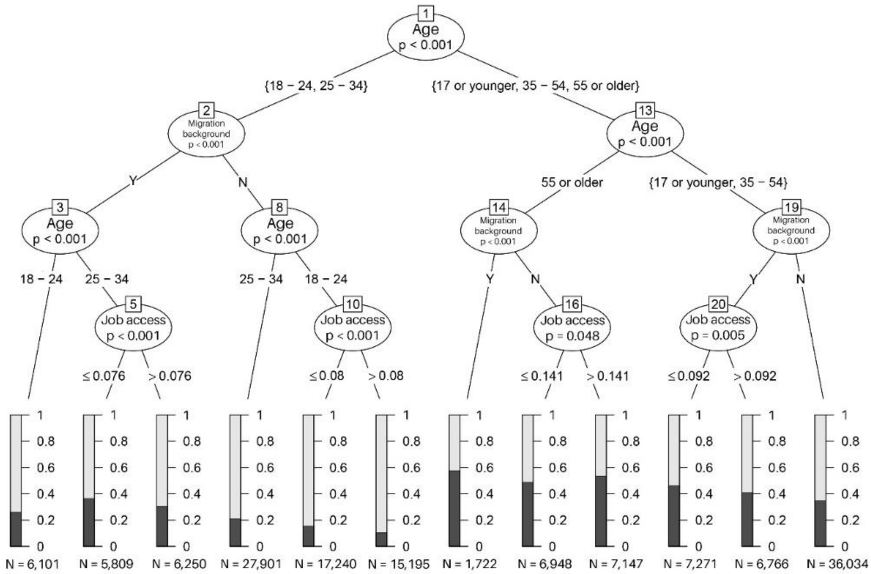

Fig. 31. Conditional inference tree for the probability of long-term unemployment for the variables job access, age and migration background

The right hand side shows higher probabilities of unemployment for the most vulnerable age groups: the youngest (17 years or younger) and the two oldest (35 to 54 years and 55 years or older) age groups. For the former, this is primarily related to the absence of a higher degree or experience in the field, whereas the latter have difficulties finding a job due to higher wage costs and a shorter employability. These inequities are reinforced by the higher probabilities for job seekers with a migration background. Interestingly, higher job accessibility negatively affects the probability for long-term unemployment for elderly job seekers without a migration background, whereas job seekers in the age groups of 17 years or younger and 35 to 54 years with a migration background do not benefit from higher accessibility.

6.6 Conclusion and discussion

The proposed research aimed to address the limitations in existing studies on the relationship between job accessibility and long-term unemployment by applying a person-based, spatio-temporal accessibility measure that incorporates job seekers' qualifications and preferences as well as job openings' requirements. The calculated accessibility levels indicate each job seeker's access to suitable opportunities while accounting for job competition by other candidates with similar employment profiles. Subsequently, a predictive model was established to assess the relationship between long-term unemployment, the calculated job accessibility levels and a job seeker's socio-demographics and employment preferences. The weighted number of accessible opportunities was negatively related to the probability of long-term unemployment, which confirms the hypothesis that a better access to jobs aids in combatting unemployment. Nonetheless, the results of the logistic regression model constructed for a train dataset highlight various inequities for the case study area of Flanders, Belgium. Job seekers with a migration background and with a higher age have higher probabilities of long-term unemployment. Moreover, job type and education play an important role in defining a job seeker's chances to find a suitable job. The overall predictive accuracy of the proposed model was tested for the test dataset and proved to be over 70%. Assessing the AUROC values indicated the moderate to strong predictive capacity of the variables of migration background and age. A conditional regression tree was constructed to support the inequity claims derived from the regression mode. Resultantly, the regression tree noted job seekers aged 17 years or younger, 35 to 54 or 55 years or older with a migration background as the most vulnerable population segments.

These findings have important ramifications for policies aimed at improving job accessibility and, resultantly, overall employment rates, especially for those groups in a disadvantaged position due to spatial factors or their individual socio-demographic status. The spatial concentration of high accessibility values in urban environments does not coincide with the relatively higher number of job seekers. This mismatch indicates the possibility of other influencing factors, such as job discrimination based on race, gender or age, but also possible language barriers or cultural differences, which are more apparent in urban settings. Another factor are the increasing standards for job seekers, leading to a longer process of finding a suitable job that correlates with the job seeker's high demands.

The public employment agency aims to counter this issue by focusing more on a job seeker's competence than on education or working experience. Although the results indicate the importance of the existing spatial mismatches, the alignment of training and education to answer the job market needs should remain the primary policy focus, especially as the current number of job openings strongly surpass the number of job seekers. The logistic regression model highlighted significantly higher probabilities of long-term unemployment for lower educated job seekers. Providing adequate possibilities of continuing education to job seekers will strongly improve the employability of job seekers in Flanders. The constructed decision tree highlights that policies focused on training continuation should be developed parallel with persisting in combatting the looming deterioration of the job accessibility for vulnerable segments of the population. Therefore, spatial planning should counteract the progressing suburbanization of disadvantaged groups from the urban labor markets to affordable housing markets in the smaller agglomerations, for example, by enhancing social housing investments in the labor market cores. In addition, especially in the peripheries of the larger conurbations such as Brussels, policies should prevent the suburbanization of low-skilled jobs towards municipalities that are not well connected to the public transport network, in order to preserve a good spatial match of demand and supply on the labor market. Finally, transport policies should be aligned with spatial planning providing opportunities for both workplace and residential Transit Oriented Development as well as accommodating better infrastructure for active transport modes.

There are some limitations that should be considered for future research. First, although increasing social, economic, spatial, temporal and behavioral aspects are taken into account, the complexity of existing measures may contravene the interpretability and usability for policy makers and planners (Cheng & Bertolini, 2013). Nonetheless, more accurate measures have the ability to provide more precise insights in individual aspects of transport disadvantage and social exclusion. Second, the proposed empirical analysis solely accounts for the job seekers and job vacancies registered at the public employment agency. This results in an underestimation of both job opportunities and labor market competition for unemployed job seekers. On the one hand, employers may have vacancies that are not registered at the public employment agency. These 'informal' vacancies, however, will not strongly impact unemployed job seekers' opportunities, as they are most likely filled in by suitable employees within the employer's own network. On the other hand, employees who are still employed elsewhere and are voluntarily seeking for a new opportunity will influence the competition factor for unemployed job seekers, especially for specialized, high-end jobs. In addition, this research considers the public employment agency as the only (in)formal information provided to the job seeker. However, personal contacts can additionally play an important role in matching job seekers to vacancies (Calvó-Armengol & Zenou, 2005; McDonald, 2010). Third, each job seeker's residence, socio-demographics and job preferences are regarded as fixed and immutable. As such, this research fails to address the possibility that individuals, for example, change their residence, obtain an additional qualification or broaden their scope of preferences in order to have access to more job opportunities. Nonetheless, the predictive model provides interesting insights in what variables impact unemployment duration and, therefore, the most beneficial variables to alter in order to enhance one's opportunities. Moreover, the proposed research does not account for all individual preferences and skills that may affect the probability of finding a job. In addition to education level and preferred profession, various other relevant factors impact the suitability and/or attractiveness of a specific vacancy (e.g., salary preferences, fixed versus temporary contract type, required relevant experience in the field, etc.). Collecting qualitative, detailed information on job seekers' specific preferences and skills – for example through constructing a database containing specific information on the personal level – would allow for an even more elaborate measure of job accessibility. However, collecting this data through an extensive survey was beyond the scope of this research. Moreover, this might prove difficult due to strict privacy concerns in Belgium in collecting and using personal information. Fourth, personal aspects of travel behavior and believes can influence an individual's opportunities. Job seekers with a driver's license, for example, were considered to own and use a car, notwithstanding the fact that this person might opt for alternative transport modes because of considerations of financial cost, security, or personal conviction. Conversely, individuals without a driver's license can act as a passenger for a colleague or acquaintance working in the vicinity or utilize shared motorized transport organized by the firm or company. In addition, because this study focuses on job seekers who are unemployed, it does not incorporate financial aspects into the equation. However, affordability strongly influences the ability to own a car or use public transport and has the ability to further widen existing transport equity gaps beyond those highlighted in this study. Future research should focus on addressing this issues to assess the relationship between job accessibility and unemployment duration in a more detailed manner.

Acknowledgement

The financial support from the Flanders Innovation & Entrepreneurship (VLAIO) is gratefully acknowledged. Additionally, the authors would like to thank the Flemish Employment and Vocational Training Agency (*Vlaamse Dienst voor Arbeidsbemiddeling en Beroepsopleiding* or VDAB) and the Brussels employment agency Actiris for providing the data on such a detailed level as well as informing the authors on specific limitations inherent to the study area and topic.

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Chapter 7: Conclusion and discussion

We should be aiming for the poor classes' independence of systems that the middle classes have created. Therefore, along with health care, employment, or education, transportation should be defined as a basic right: the right to be (im)mobile.

Karen Lucas, 2016

This closing chapter addresses the relationship between the background and theoretical framework (Chapter 1) and the case studies (Chapters 2-6). The first section summarizes the case studies' main findings, and how they support the transition from place-based to person-based accessibility measures. In addition, the author determines to what extent the case studies have sought to provide answers to the problem statement and research questions as proposed in Chapter 1. In the second section, the limitations inherently related to the use of complex person-based accessibility measures are discussed. A constraints-led approach is proposed as a guiding principle for distributive justice and transport equity appraisal. This approach recommends three focal points for future research and policies aimed at incorporating equity in transport-focused projects or accessibility studies.

7.1 Where are we now?

7.1.1 From place-based to person-based accessibility analysis: research through case study examples

This dissertation examined the impact of temporal and personal restrictions on transport equity. Moreover, it delineated accessibility analysis that solely accounts for spatial restrictions as inadequate for equity appraisal. Therefore, five case studies were selected with an increasing complexity in accessibility analysis. In four of the case studies, research was conducted for (part of) the region of Flanders, and one case study was situated in the Wasatch Front Region, Utah. All of the case studies examined access to services that are considered crucial for a sufficient quality of life (e.g., health care in Chapters 2 and 3 or employment in Chapters 3, 4 and 6). The proposed studies are mainly quantitative, with a strong focus on GIS calculations (in ArcGIS with automation in Python) and statistical analysis (in R).

Fig. 32 illustrates how the different chapters or case studies are situated in the theoretical framework proposed in Chapter 1. In addition to spatial restrictions, the case studies encompass various temporal and personal restrictions in the transport network, demand and supply to facilitate the transition from place-based to person-based accessibility measures. However, Fig. 32 also shows that the temporal restriction of activities' opening hours have not been incorporated as temporal constraints into this dissertation. The author refers to the case studies examined by Delafontaine et al. (2011) and Weber and Kwan (2002) for further reading on this topic.

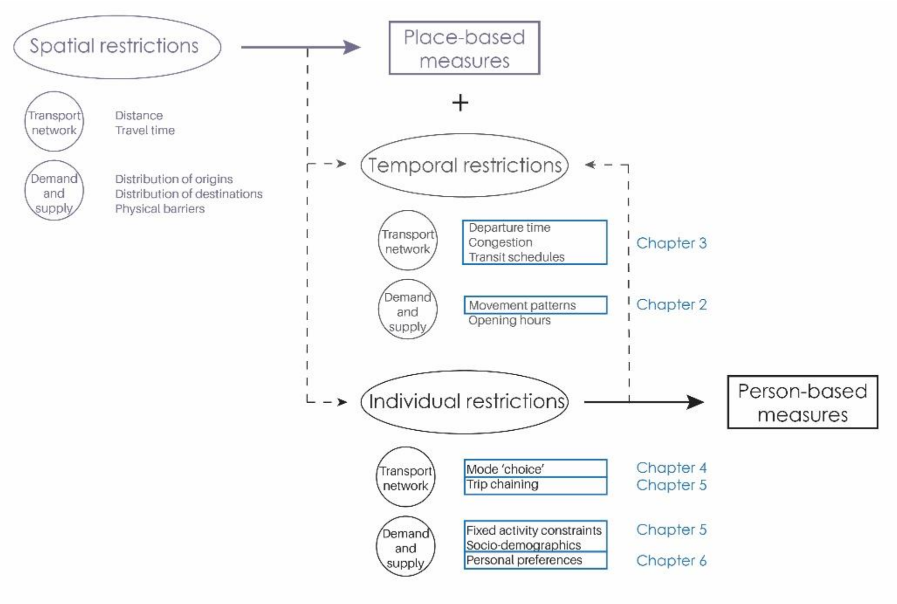

Fig. 32. Positioning of the doctoral dissertation chapters in the theoretical framework (adaptation to Fransen and Farber, forthcoming)

The first case study (Chapter 2) explored to what extent access to possible opportunities can differ when more elaborate, time-based accessibility measures are applied. The proposed preliminary time-based measure extended a commonly applied spatial accessibility measure by accounting for trip-chaining behavior. Irrespective of the accessibility metric's accuracy, the proposed study revealed the impact of including the commute in assessing access to childcare services in the province of East Flanders. Significantly different patterns of accessibility levels were found for the commuter-based method in comparison to the purely spatial floating catchment area method. Therefore, this case study acted as a valuable first step in implementing the proposed theoretical framework: the introduction of temporal constraints in accessibility analysis. Because of its adaptation of a FCA method commonly applied in the domain of healthcare and, therefore, specific use, this study will primarily be consulted in this specific research domain. The question remains, however, if more elaborate metrics succeed in highlighting disadvantaged areas and, consequently, in evolving towards a more equitable distribution of benefits.

The second case study (Chapter 3) sought to answer this question by additionally introducing temporal constraints in the transport network to determine public transport provision to primary services in the region of Flanders. Therefore, an aggregated, spatio-temporal accessibility measure was constructed. Defining transport gaps aids in optimizing the provision and, therefore, the transport network in general. The comparison of the public transport provision and the specific needs based on the socio-demographics allows to define pockets of transport disadvantage as those areas where the provision does not meet the needs. In addition, possible inefficiencies where the provision surpasses the need are highlighted. This is an important step towards a more efficient demand-driven model (bringing people to a destination they desire to access) instead of an arbitrary provision-driven model (providing mobility to people without any guarantee of actual accessibility). Moreover, this analysis allows to determine who is in need of public transport and if this person's need is met through the existing transit infrastructure. This study will be relevant for research in the specific domain of public transport analysis that assesses how both the need and the provision can be modeled.

The third case study (Chapter 4) further explored the use of spatio-temporal accessibility measures to highlight disadvantages, and introduced the person-based constraint of mode choice – or more specifically, transport mode dependency. The case study examined multimodal accessibility levels to employment opportunities for the specific disadvantaged group of job seekers in the region of Flanders. The outcome provided a first distinctive example of transport inequity in the relative needs, as 80% of the individuals with a driver's license have sufficient access to employment opportunities in comparison to only 20% for those without a driver's license. Employment opportunities for the latter are also distributed inequitably in space, as higher levels of access are strongly concentrated around the cities of Brussels, Roeselare and Kortrijk. In addition to driver's license ownership, an individual's education level was identified as an important indicator for job seekers' access to possible jobs. Lower educated job seekers have a 7% lower access to job opportunities than highly educated job seekers. Both transport and employment policies can directly target these specific population groups to provide more opportunities to those in need. Nonetheless, the aggregate level of analysis hinders a precise, person-based assessment of job seekers' employment opportunities that exactly match their specific job preferences and skills. This study will primarily be consulted for more qualitative research specifically examining the relationship between multimodal accessibility (or car use in particular), education level and employment.

In addition to the majority of studies in the domain of transport, the first three case studies started from the premise that providing more accessibility leads to a stronger embeddedness in society and, moreover, will automatically benefit the population segments most in need. The fourth case study (Chapter 5) challenged this premise by constructing an accessibility approach to determine the relation between an individual's accessibility and his/her participation in discrete activities. Therefore, a person-based accessibility measure was constructed that accounts for an individual's complex spatial and temporal constraints. The validity of the accessibility-participation relationship was tested for both this person-based and an additional place-based accessibility measure, because of previous studies' inconclusiveness when applying place-based measures. The findings showed that – in contrast to the counterintuitive outcomes for the place-based accessibility – higher levels of person-based accessibility are positively related to more participation in activities. In addition, the case study highlighted important ramifications in understanding the way accessibility is distributed amongst the population and indicates that, even when applying the most accurate accessibility measure, accessibility gains primarily affect people who are already in an advantaged position. This calls for an accessibility focus on a local, quasi-personal level, if issues of equity are considered as a mandatory component of transport policies. This study is the pioneer in identifying the relation between person-based accessibility and participation in discretionary activities, and as such will have a strong scientific impact on all domains related to accessibility analysis, and more specifically on those studies that apply person-based accessibility measures and aim to validate the use of person-based accessibility measures.

The fifth case study (Chapter 6) continued on the use of person-based accessibility for equity appraisal, but additionally introduced personal preferences into the analysis. In this case study, the provision of employment is matched to the population's needs by precisely connecting job seekers in the regions of Flanders and Brussels to jobs that match their competences and preferences. In addition, aspects of equity are accounted for by relating the number of accessible, suitable opportunities to the individual's unemployment duration. Herein, access was negatively related to the probability of long-term unemployment. However, complementary to the previous case studies, the results showed that improving accessibility as it is currently conceived does not primarily benefit those population groups in need (e.g., the elderly or job seekers with a migration background). Moreover, the case study concludes that policy implications should aim to go beyond spatially targeted interventions. However, this chapter also questions transport policy's ability to tackle equity issues without a strong connection with other policy domains (e.g., spatial planning, education or poverty). This study will be valuable for all research aiming to improve employment accessibility research, as it succeeds in identifying accessibility on a highly detailed level by taking into considerations competences and preferences on an individual level.

Overall, the proposed methodologies only attain a moderate level of novelty in the field of academics, as the benefits and drawbacks of incorporating temporal and personal constraints have been assessed to a large extent in the last decades. Consequently, this limits the dissertation's general transformative impact on the state of the art or practice. The time-geography concept is a well-studied research topic and has been applied in a wide range of case studies (e.g., research by Mei-Po Kwan, Harvey Miller, Karst Geurs, etc.). In addition, a number of detailed person-based accessibility measures go beyond the level of detail of the case studies proposed in this dissertation (e.g., research by Tijs Neutens, Antonio Páez, etc.). Nonetheless, the main overall novelty of the dissertation is found in the link between more detailed accessibility measures and equity in transport research and policy, mostly examined for specific subdomains of transportation research with a specific policy focus (e.g., access to health care or employment opportunities). Herein, the case studies can be aligned with case study examples by Izhtak Benenson, Michael Widener, Steven Farber or Tijs Neutens. However, existing research examples still fail to capture every aspect of equitability in one overarching accessibility measure, as each case study is context specific and affected by varying constraints. As a result, each of the case studies is characterized by a specific novelty, making the case study worthwhile to consult for future academic research. The case study in Chapter 2, for example, is still the only adaptation of the commonly applied 2SFCA that accounts for commuting behavior. Although more detailed and correct measures of accessibility exist (e.g., the modified 2SFCA or the three-step FCA), the CB2SFCA remains the only adaptation that surpasses the purely static representation of accessibility. Another example is the case study in Chapter 5, where the use of a person-based accessibility measure successfully addresses the relationship between accessibility and activity participation, which had not been clearly defined in previous research. And Chapter 6, for example, is one of the first studies in the subdomain of job accessibility that assesses unemployed job seekers' access to job openings. Moreover, it is the only existing case study that examines this accessibility on such a detailed scale.

7.1.2 Addressing the problem statement and answering the research questions: the general conclusion

The proposed case studies directly address the problem statement by demonstrating how person-based accessibility measures are applied to deal with distributive justice. The outcomes of the conducted case studies confirm the hypothesis that person-based accessibility measures are better suited to address equity appraisal, as they allow researchers to incorporate spatial, temporal and individual restrictions into the accessibility analysis. More complex measures go beyond the purely spatial projection of our society, and account for a wide range of restrictions that additionally shape a person's opportunities. As a result, person-based accessibility measures are adequate in identifying issues related to social inequity and transport poverty.

Overall, the case studies have additionally addressed the research questions as projected in Chapter 1. Fig. 33 denotes two important drivers for transport equity appraisal. These structuring mechanisms are related to the research questions and encompass both the various restrictions that structure accessibility and the measures used to examine it. First, incorporating more restrictions leads to an increased demand for GIS complexity and stricter data requirements. As a result, the application of more elaborate accessibility measures in academic research is limited (vertical axes in Fig. 33). Second, temporal and individual restrictions act as stronger facilitators for the occurrence of disadvantages. However, policy interventions are mainly focused on spatial restrictions because accounting for temporal or individual factors strongly enhances the complexity of the issue at hand and, therefore, of the proposed intervention. Although more detailed ideas on accessibility have emerged in recent years by incorporating temporal (e.g., congestion pricing or time-variable parking prices in urban settings) or personal aspects (e.g., solutions to the last mile issue in the concept of basic accessibility or the concept of mobility as a service), place-based measures inadequate in addressing (transport) disadvantages and equity issues remain the standard for policy interventions (horizontal axes in Fig. 33). At the moment, more elaborate concepts are not qualitatively implemented in policy interventions, and there is still a significantly long way to go to bring them out of the realm of conceptual thinking and (public) debate. The impact of both mechanisms is explained in more detail by defining how the case studies in this dissertation specifically answer the research questions.

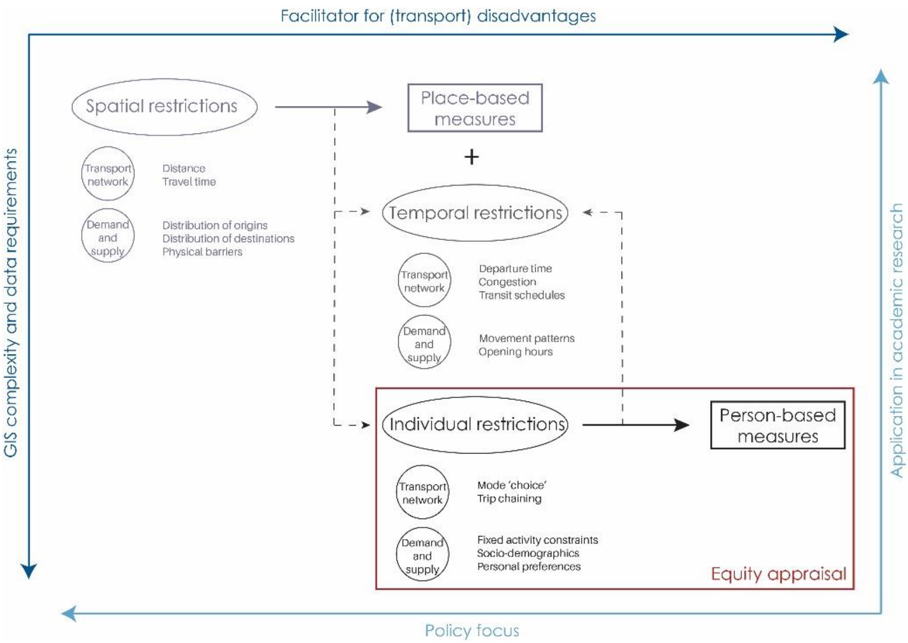

Fig. 33. Adapted theoretical framework as dissertation conclusion (adaptation to Fransen and Farber, forthcoming)

RQ1: What benefits do geographic information systems (GIS) provide to person-based space-time accessibility analysis?

Clearly, accessibility analysis benefits from the complex capabilities of a GIS. The software was applied in each case study for one or more components of the accessibility analysis for the study area, especially when extensive travel time calculations were needed. As the case studies – and, therefore, the applied datasets – became more complex, the functionalities available through a GIS were enhanced by automating the calculations in a programming language (in this dissertation mainly in Python). This combination allows the researcher to perform highly complex travel time calculations in a fast-paced and automated manner. The more accurate these results, the more detailed interpersonal differences in accessibility can be examined. Nevertheless, from a critical point of view, we must indicate that solely the use of a GIS is not sufficient in adequately addressing equity issues. A GIS can handle spatial queries very well, new capabilities allow a GIS to assess temporal restrictions (cf. Esri's Network Analyst's 'Add GTFS to a Network Dataset' extension) and large datasets, yet to answer specific, person-based equity issues, more is required from the user than merely using a GIS. As mentioned earlier, extensive data on an individual level is necessary for person-based accessibility analysis for equity appraisal: information on socio-demographics, travel and time use diaries, etc. Prior to performing elaborate GIS analyses, one first needs to understand the data requirements related to a specific issue, correctly collect the required information, convert this information to ready-to-use, spatio-temporal data and, most importantly, visualize, comprehensively communicate and test the given outcomes. In addition, the capabilities of GIS stretch beyond the ones explored in this dissertation (querying and analyzing (a)spatial information). Data management, for example, supports the user in structuring the data, therefore, limiting complexities and decreasing the analyses' calculation times for large datasets (e.g., PostgreSQL in combination with PostGIS). Moreover, the use of GIS for visualizing the results was currently limited to constructing static maps, charts and tables. Recent developments in webGIS, interactive maps or online GIS applications provide numerous opportunities to depict findings in a more dynamic and inclusive way for a wide range of users.

- RQ2: To what degree do temporal and personal restrictions facilitate (existing) transport disadvantages?

The case studies illustrated the benefits of incorporating temporal and personal restrictions into accessibility analysis: various underlying mechanisms of disadvantages become visible that were not apparent when a purely spatial analysis was applied. However, how these restrictions affect disadvantages and, resultantly, the degree to which transport disadvantages manifest themselves has proven hard to determine. This is mainly related to the absence of a clear definition – both in policy and in academic research – of what is considered as a disadvantage. Accordingly, there is little agreement on the suitable theoretical foundation for measures of justice in accessibility. Multiple case studies enabled highlighting which population groups or individuals were in a beneficial or disadvantaged situation. However, disadvantages were only determined relative to other socio-demographic groups or individuals, without any definite threshold to actually label someone as disadvantaged. Moreover, a person's actual accessibility is also determined by aspects of comfort, safety and perception (Bramley and Power, 2009; Winters et al., 2013). A location might be accessible within the scope of his/her spatial and temporal constraints, however, a low walkability or bikeability can hinder that person in actually reaching the desired destination. These aspects have not been thoroughly assessed within the scope of this dissertation. Herein, the spillover from academic research on equity topics to policy implementations remains limited. This goes to show that a clear policy stance on the concepts of social and transport disadvantage, exclusion and transport poverty in addition to a better cooperation between academic research, policy and practice are fundamental before this research question can be addressed properly. The Utah case study in Chapter 5 distinctly notes the possible fallacies of using place-based accessibility measures for equity appraisal. Contrastingly, person-based accessibility measures prove to be more accurate in defining equity issues. Therefore, they act as a more reliable base for defining an accessibility framework for equity appraisal in (transport) policy.

- RQ3: Is access to opportunities distributed equitably in Flanders, Belgium? If not, what types of disadvantages exist and who is affected by them?

As mentioned in the introduction, the study area of Flanders is characterized by a dispersed land-use pattern with high concentrations of opportunities in the most urbanized areas. In addition, Flemish citizens are highly car oriented, especially in the suburban and rural parts of the region. These phenomena are reflected in the case studies results, and were considered as the cause for various types of disadvantages. For example, different case studies highlighted that a modal-based transport disadvantage is apparent for Flanders. Herein, car users have accessibility levels that are multiple orders of magnitude higher than public transport users or cyclists. This paradigm mainly manifests itself in the rural parts of the region (e.g., large parts of the provinces of West Flanders and Limburg), whereas inhabitants of urban areas have a relatively higher accessibility. Temporal variations in provision, however, can alter this imbalance. For example, congestions negatively impact the travel cost for car users, and higher frequencies during rush hours positively impact the travel cost by public transport. These inequities directly affect people who are in a socially disadvantaged position because of the inability to use a car, for example, due to the high purchase and maintenance costs. The case study on access to employment opportunities in Chapter 4 clearly showed the impact of not owning a driver's license on the number of employment opportunities a job seeker can reach. Moreover, other socio-demographics have repeatedly proven to be strongly related to transport disadvantages (e.g., income, age or gender). In Flanders, lower levels of accessibility to opportunities are currently found for those who are worse off, and, therefore, in a stronger need for targeted policy support.

- RQ4: Can policy support based on an accessibility framework assist in countering social exclusion?

Both existing literature on social exclusion and the case studies proposed in this dissertation show the importance of accessibility analysis in pinpointing manifestations of social exclusion. As a result, improving accessibility should be a primary goal in a wide range of policy domains. However, two important limitations should be addressed to actually counter social exclusion. First, in coherence with RQ2 and RQ3, an evolution from place-based to person-based accessibility analysis is necessary. To this date, place-based accessibility measures are common practice for policy support, because of their simplicity and ease of use. The high data requirement and complex operability of person-based accessibility measures raise the threshold for implementing any of the more elaborate measures. Nonetheless, the case studies show the importance of applying the most suitable accessibility measure while taking into consideration the specific research topic. Second, the case studies in Chapters 5 and 6 show that providing more accessibility does not necessarily benefit those in need. Although elaborated for a different study area, the analysis for the Utah case in Chapter 5 indicates that improving accessibility will primarily benefit those who already have a moderate accessibility to discrete activities. Chapter 6 indicates that given the current transport infrastructure and distribution of opportunities and inhabitants in Flanders, various vulnerable groups (e.g., elderly or inhabitants with a migration background) are in a disadvantaged position in finding suitable employment. This highlights that policies related to improving employment rates (or diminishing long-term unemployment) should primarily target these specific groups when striving for a more equitable distribution of transport benefits.

The next section continues on the dissertation conclusions and defines the future research and policy directions we as researchers, practitioners or policy makers should take to put theory into practice.

7.2 Where are we heading?

The series of studies conducted in this doctoral dissertation support the need for more detailed measures of accessibility and a transition from place-based to person-based accessibility metrics. However, this transition is not a straightforward one, as several limitations should be addressed before a workable accessibility-based equity framework is constructed. Therefore, an adaptation of a constraints-led approach is proposed to answer the current shortcomings in academic research and policy.

7.2.1 A constraints-led approach for equity appraisal

The major issue remains the development of equity appraisal based on the spatial, temporal and individual constraints that impact the distribution of accessibility benefits. The dissertation's case studies showed that various types of transport inequity exist for the study area of Flanders and that they have currently not been addressed in the majority of academic research and policies. This is mainly related to two major limitations: first, the absence of a clear definition of what is considered as a transport disadvantage and what is understood as an equitable distribution of transport benefits, and second, the complexity in defining and examining the complex spatial, temporal and individual constraints influencing accessibility due to calculation complexity and data requirements. The author proposes an adaptation of the constraints-led approach (also known as the Dynamical Systems Theory), which is a perspective often applied in the domain of ecology to represent how ecosystems are open, dynamic systems that organize themselves to attain stability (e.g., in sport psychology (Renshaw et al., 2009) or in biology (Furusawa and Kaneko, 2012)). Herein, constraints – or boundaries that shape the emergence of behavior – interact with one another to construct a stable situation.

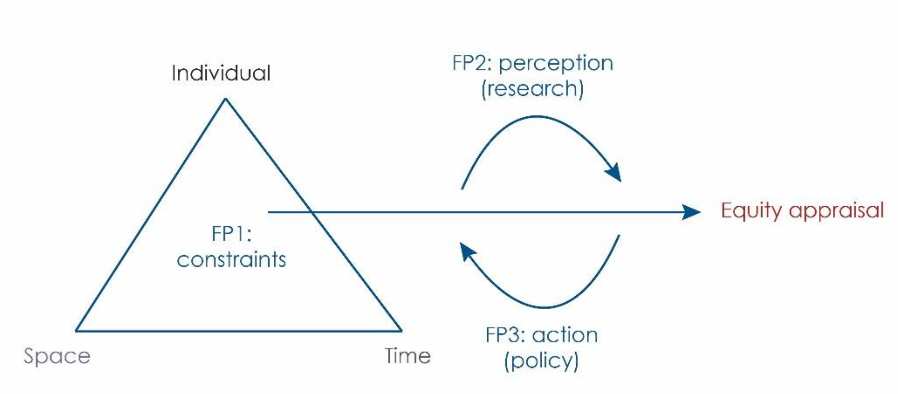

Fig. 34. A constraints-led approach for equity appraisal in transport

This concept can be projected on the application of equity appraisal in the domain of transport. Herein, the constraints would be the three dimensions as proposed in the theoretical framework: space, time and the individual (Fig. 34). These constraints interact with one another on various levels. Consider the example of a father who is restrained in space and time because he has to pick up his daughter from soccer practice, which requires him to be at a certain location (the soccer field) at a given time (7 pm). If one of the dimensions would change, the constraints-based approach states that complex behavior normally regulates itself until a stable situation is reached. This is also the case for the spatial, temporal and individual restrictions that impact accessibility. If in the same example the father has two children going to different soccer teams, he would be additionally restrained in space and time. As a result, he has to spend a larger portion of his time budget to picking up his children. The father as a "dynamic system" regulates itself by altering the other dimensions. However, if self-organization is not possible, inequitable situations can occur: varying constraints for different individuals can lead to conditions where one has access to certain opportunities while the other does not. Given the same example, the father of two might not be able to stretch the time dimension sufficiently to pick up both children from soccer practice due to constraints related to his work activity (e.g., he works evening shifts). Stability is not attained and an inequitable situation occurs, as the children are unable to attend soccer practice due to the combination of spatial, temporal and individual constraints for father and children.

7.2.2 Three focal points for implementing the constraints-led approach

In the constraints-led approach, (academic) research and policy play an important supporting role in attaining the goal of transport equity (Fig. 34). The former is tasked with providing information on the constraints that might create social exclusion due to transport inequity and defining what type of disadvantages occur for whom. The latter has to bring theory into practice, by adapting (transport) policies to address the various constraints that caused the inequitable situation. Consider again the example of the father. One first has to assess that an inequitable situation occurs, for example by identifying the mismatch between the father's individual accessibility and the children's needs. This might be achieved through a case study on person-based accessibility to recreational activities for the study area where the father lives. Second, policy has to determine if this disadvantage is sufficiently severe to designate the inability to reach soccer practice as a cause for social exclusion that should be addressed, and if so, what type of interventions are needed. In addition, policy has to define what priorities to take, as a totally different situation is presented should the father's children be hindered to reach primary health care instead of a recreational activity. An important side note to consider is that policy cannot address every notion of inequity, especially as a large number of situations are influenced by personal choices and preferences. In conclusion, three focal points (FP) are defined that act as a foundation for future academic research and serve as guidelines for policy reflections or recommendations.

1) FP1: delineating the constraints and defining the concepts of social and transport disadvantages, transport equity and social exclusion

A first focal point highlights the need for a uniform and clear delineation of which (spatial, temporal or individual) constraints impact accessibility. Herein, the importance of non-spatial constraints is often overlooked. This results in the majority of work in academia, policy and practice to be based on overly simplified, place-based views on transportation and spatial planning. Especially for research on equity appraisal, using aggregated, spatial analysis does not provide detailed insights on the mechanisms truly at work. This is partly due to the strong focus on mobility that has reigned throughout (Flemish) transport and spatial planning policy during the past decades. Providing mobility to an individual to overcome the spatial boundary of distance was the starting point for the right for basic mobility as established in the Flemish decree on Passenger Transport (*decreet* *personenvervoer*). This decree stated that every inhabitant living in a residential area should have access to a public transport stop with a minimum trip frequency and within a certain distance of the home location. Although interesting from an equity perspective, this notion was constructed regardless of the public transport system's ability to bring individuals to the destinations they wished to reach. However, issues related to efficiency have brought a transition from the idea of basic mobility to basic accessibility, with a focus on better connecting the transport provision to the need for transport. Incorporating temporal and individual restrictions in the implementations of the novel transport focus of basic accessibility is a crucial step towards a qualitative transport network that aims for an equitable distribution of its benefits for all possible users, especially those in need. Herein, it is important to note that both transport users and desired destinations can be highly dynamic. The transport user dynamics have been addressed in this dissertation, but throughout the different case studies, facilities have been considered as fixed in place and time. However, the provision of services is evolving to a more dynamic concept (e.g., mobile services vans, e-commerce, telecommuting, etc.). Future accessibility analysis should aim at incorporating this evolution into the accessibility metrics.

The major limitation remains the absence of a clear definition of what is considered as equitable and what accessibility thresholds determine if a person is in a disadvantaged position. Policies aimed at improving the distribution of transport benefits should take a clear stance on what equity means and, equally important, assess if the constructed notion of equity is attainable. Although any definition would be arbitrary, it would proof useful. It is important to note that the utopia of an ideal configuration of the transport network with equitably distributed benefits is far from realistic if financial or infrastructural restrictions hinder its implementation. Moreover, personal preferences and choices strongly influence our perception of equity. For example, is it inequitable that inhabitants of rural areas have lower access to job opportunities than city dwellers if they chose to live at large distances? And what if housing policies make living in the city unaffordable for the larger part of the population or transport policies fail to provide adequate alternatives to car travel in these rural regions? Nonetheless, policies in various domains should strive to address equity as correctly as possible. The COST Transport Equity Analysis group workshops and meetings, and the resulting book 'Measuring Transport Equity' currently being published provide a strong academic research base for researchers, policy makers and practitioners interested in equity appraisal.

2) FP2: perception and communication of possible transport-related equity issues through (academic) research

A second focal point delineates the role of (academic) research in understanding how different types of constraints impact accessibility. Herein, the extensive data requirements when using GIS for person-based accessibility measures play a crucial role. Currently, available data is often limited to purely spatial information (e.g., locational point data on possible activity locations, without, for example, information on opening hours). Moreover, this information is often aggregated and, consequently, hinders an adequate representation of transport-related equity issues on an individual level (e.g., zonal data containing socio-demographic information). The major limitation for the aggregate approach is that it assumes that every inhabitant in the same geographical zone is affected by similar (time-)geographic boundaries. The data requirements for person-based accessibility measures are more extensive and range from basic temporal information such as historic speed data for a road network to more detailed datasets such as individual travel diaries. This results in a more extensive process of data collection, prior to the possibility of actually conducting a space-time analysis. This costly and time-consuming process poses a strong barrier to the application of person-based, space-time accessibility measures, as researchers mostly do not have the time to collect the data on a highly detailed level. In addition, the cost for buying similar data is exceptionally high due to the significant economic value (especially for big data).

Two possible solutions for the limitation related to the data requirements and calculation complexity can be explored. First, the data collection could be part of a policy strategy that strives for more detailed accessibility analysis. Publishing this information as open, ready-to-use data would strongly reduce the barrier for equity research in theory and practice. The Research on Travel Behavior in Flanders (*Onderzoek Verplaatsingsgedrag* or OVG) is a suitable example of an initiative where highly detailed information on travel behavior on the household and individual level is collected for Flanders over a 5 year period (from 2015 to 2020). However, the number of participants remains relatively low, the travel diary is limited to a 24-hour period and, to the author's knowledge, the survey is the only qualitative dataset on (daily) travel behavior in Flanders. Stronger policy efforts should be directed to supporting the qualitative collection of publicly available datasets suitable for space-time analysis. Herein, the use of relatively new techniques for data collection could provide an answer to the high data requirements. GPS-tracking, WiFi-tracking or CDR-tracking (tracking of cell phone data) allow researchers to collect more elaborate information on transport users' spatio-temporal travel patterns and behavior. An alternative option is the collection of online data through data scraping (Cameron, 2009, Yang and Ma, 2015). In addition, policy decisions (both in governmental agencies and companies) are increasingly supported through big data analysis, such as data mining, predictive or hierarchical modelling or machine learning. Nonetheless, the users would still require sufficient skills in GIS to perform complex analyses. The majority of these techniques, however, do not succeed in collecting data in an exclusive manner. Moreover, more detailed information also leads to more computational complexity, more required storage capacity, longer processing times and other issues related to the use of big data.

Consequently, a second solution complements the first, and states that a better cooperation between academic research and policy would benefit the use of elaborate accessibility measures. Although scientific research could provide valuable insights in the underlying mechanisms of accessibility and related equity appraisal, to date, only a small portion of academic studies makes it to the level of actual policy making. Moreover, the duality between detailed measures that represent reality more accurately and comprehensible, ready-to-use outcomes is one of the major challenges in bridging the gap between academic research and policy. The communication on the case study findings (e.g., to the public transport agency *De Lijn* or the Flemish employment agency *VDAB*) demonstrated that more concise ways to represent, visualize and communicate the findings on person-based accessibility analysis are necessary. Herein, experts in the field play an important role, as they have the ability to tell the 'transport side of the story' to people that are unfamiliar with this point of view. Therefore, meetings where planners, transport experts, designers, etc. work together and collaborate are an important way of exchanging information and providing a base for better collaboration. In addition, accessibility should be addressed as a widely known concept in those various policy domains and more, specifically, equity should become a fixed topic in the policy agenda.

3) FP3: policy-based interventions for transport equity appraisal

A third point to work on is the actual implementation of the accessibility framework in policy and practice to address existing disadvantages in the study area of Flanders. As mentioned in the previous section, various types of disadvantages exist among a wide range of population segments. The most important factor influencing the efficiency of future transport policies and investments is correctly understanding individuals' transport needs. For access to employment, for example, different transport needs arise for various population groups in comparison to the accessibility to other services (e.g., health care or education). Nonetheless, assessing inequities in multiple domains helps us to define the measures that have the strongest impact for those most in need. This complements the general idea of the right for basic accessibility, as the aim is to provide 'tailor-made transport' on the lowest hierarchical layer of the transport network: provide a solid transit grid that links locations with high priorities, and focus local initiatives on connecting disadvantaged areas or groups to this grid. Policies should strive to directly counter existing disadvantages and manifestations of social exclusion, for example, due to the strong car dominance in Flanders.

The existing high accessibility gap between car users and users of alternative transport modes indicates the necessity to invest in public transport and cycling infrastructure. The past decade has shown some significantly positive evolutions: cities exclude cars from their city centers (although not particularly from a social equity perspective), transport policies begin to understand the negative effects related to the provision of extra highway lanes for more private transport capacity and planning is repeatedly shifting to a more density and proximity-based approach. However, if transport by car is discouraged, alternative transport modes should be qualitative enough to act as a worthy replacement, which is currently not the case, as illustrated by the case studies. Moreover, investments in public transport or infrastructure for active travel modes should be subjected to the same equity criteria as investments for private motorized transport. Herein, new (possibly disruptive) mobilities such as ride sharing, new types of public transport services, play a pivotal role. Those mobilities will strongly influence the transportation landscape in the immediate future and, therefore, should be considered into the equation. In addition, more and more civilian-led ideas and projects arise and additionally impact the distribution of transport benefits. A clear policy stance on how those different mobilities and actors intertwine is a necessity, and transport policy should clearly address the various actors. Moreover, investment in alternative transport modes should be addressed from a broader stance: policy support is not limited to providing better public transport and infrastructure for active transport. It can also address these new mobilities by actively supporting initiatives such as carpooling, a company van that picks up employees, the concept of the neighborhood van ("de buurtbus"), etc.

Moreover, new types of modelling are needed. Cost-benefit analysis (CBA) is commonly applied from a very 'efficiency-focused' point of view (e.g., the study in cooperation with public transport company De Lijn), which results in a total absence of any thought on equity appraisal in the currently applied transport models. Transport policy should examine more inclusive models that go beyond planning transportation infrastructure in the most efficient way. Therefore, current transport models in standard planning and project definition processed based on traffic modelling need to be critically assessed from a holistic point of view (do they incorporate all three domains of sustainability: economic, environmental and social and do they address various policy domains). GIS can serve as a base for more inclusive transport modelling, as it allows to address issues that go beyond a purely spatial representation of accessibility. An important side note to make here is the need for more qualitative data in order to address additional constraints that impact an equitable distribution. Therefore, quantitative research needs to be related to qualitative data collection to additionally collect information on socio-demographics and personal preferences. The case-based, living lab approach-based studies by Mobiel 21 are a good example of complementary research that addresses this limitation. A more participatory and open process is recommendable, as it can allow policy to address case-specific and even person-specific accessibility issues. Transportation, and more specifically accessibility, is increasingly becoming a part of the public debate, which can bring interesting new insights that complement a (transport) planner's point of view.

In addition, the theoretical framework of accessibility for equity appraisal should be extended with qualitative research on what type of solutions are needed and the degree to which these solutions help in combatting social exclusion if eventually implemented in a test case. This also demands a strong participation from the various stakeholders to better understand the transport needs. Finally, research in the field of transportation – be it within academia or policy – should aim to better accommodate the link with other research domains, especially with spatial planning. The way people travel has a strong impact on the built environment and their quality of life, and, as such, is strongly related to, for example, spatial planning, housing or economics, or a wide range of other policy domains. In the *Witboek Ruimte Vlaanderen*, which is the predecessor for the Spatial

Planning Policy Plan for Flanders (*Beleidsplan Ruimte Vlaanderen*) approved by the Flemish government in 2016, there is little mention of the concept of accessibility, and none whatsoever on equity appraisal. A stronger link between the various related policy domains would greatly benefit the further implementation of the proposed framework.

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Mobility – or the ability to travel from one location to another – has acted as the guiding principle in transport policy and planning. To date, the premise of maximizing mobility to facilitate people's travel between different locations still reigns. This doctoral dissertation takes a clear stance in countering the promotion of personal mobility and strives for an increased focus on a fair and equitable distribution of personal accessibility – or the ability to actually reach (primary) services. The larger part of accessibility analyses currently depart from an overly simplified situation, solely taking spatial restrictions into consideration. Moreover, concepts of transport poverty or social exclusion are not addressed in the domains of transportation and spatial planning. More elaborate research that additionally accounts for temporal and personal restrictions is pivotal in better understanding the complexity of the research topic. The dissertation proposes a structural framework that supports the transition from place-based to person-based accessibility analysis and draws upon the increasing functionalities of Geographical Information Systems to examine five case studies. The developed research framework and case study findings result in various focal points and policy recommendations.