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by

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# ACTIVITY-TRAVEL BEHAVIOUR IN THE CONTEXT OF WORKPLACE RELOCATION

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# Executive summary

Travel behaviour analysis is a complex task because of the myriad of determinants influencing decision makers. The commuting trip constitutes an important travel purpose, but is not the dominant one. Because of its spatial and temporal concentration, the commuting flow is an ideal target for mobility management measures aiming at decreasing its negative externalities. Nevertheless, commuting travels are done in the frame of a more complex activity-travel chain, and some choices, whether on the short term (e.g. commuting mode choice) or in the longer term (e.g. where to live, buy a car) are done considering an ensemble of trips. Our research hypothesis is that workplace relocation, or more generally an event that strongly affects travellers' trip chains, induces different and interrelated responses. Our research aim is to gain insight into this complex decision-making process, in order to better understand its relation with transport policy measures.

# 1

# Introduction

## 1.1 Background and context

Travel behaviour analysis is a complex task because of the myriad of determinants influencing decision makers, as various elements such as land use, mode availability or mode specific attitudes influence the way travellers reach their activity locations (De Witte et al., 2014; Zhou, 2012; Van Acker et al., 2007).

Timmermans et al. (2003) provide an interesting reminder of all possible decisions made by travellers. The number of activities to perform -even if some activities are performed opportunistically (Lee & McNally, 2003), the activity location, the activity duration, the travel mode, etc. as well as the number of choices to be made are, in theory, tremendous. However, in order to optimize their resources (time and energy in this case) people tend to transform repetitive behaviour into habits (Bamberg et al., 2003; Garling & Axhausen, 2003).

Around 60% of the world population is employed (World Bank, 2016) and the commuting trip represents between one-fourth and one fifth of the total workers' daily trips (Cornelis et al., 2012). Consequently, the commuting trip constitutes an important travel purpose, but is not the dominant one. Because of its spatial and temporal concentration, the commuting flow is an ideal target for mobility management measures aiming at decreasing its negative externalities. Nevertheless, one should realise that commuting travels are done in the frame of a more complex activity-travel chain, and some choices, whether on the short term (e.g. commuting mode choice) or in the longer term (e.g. where to live, whether to buy a car) are done considering an ensemble of trips.

Transport policy measures implemented by large (private or public) institutions have however the tendency to focus on the home-to-work trip characteristics to foster a modal shift of their employees towards sustainable mode alternatives. While taking into account workplace accessibility (by car, by public transport and by soft modes) is necessary, we argue, in this research, that the complexity of the employees' activity-travel behaviour has to be taken into account.

Travel behaviour modelling is already challenging if one considers the traditional trip-based approach, but the complexity of this task is growing enormously if the environment of the decision maker is changing. Among other factors, the relocation of the employees' workplace is undoubtedly an event that has the potential to strongly affect all the commuting decisions but also all the activities that were previously inserted in the commuting tour, as well as the decisions taken to perform these tours in the most efficient manner (e.g. choosing the place of residence, in which school dependent children are enrolled, when and where to perform leisure activities, and many others). On the long run, if the dissatisfaction regarding the commuting trip remains high, workers might opt for long-term adaptation strategies such as moving residential location or quit their current job.

Our research hypothesis, or main rationale, is that workplace relocation, or more generally an event which strongly affects travellers' decision-making processes, induces different and interrelated responses. This event is likely to require the travellers to re-think of their daily routine, i.e. their activity-travel patterns, in order to mitigate possible negative impact in the travel costs. For the concerned employees, negative impacts are actually reflected in loss of satisfaction or welfare, as travellers tend to assign some ideal budget for their travelling, both in terms of time and in terms of monetary expenditures, and these may increase significantly because of this exogenous event. Hence, responses can be observed in the short run and with relatively low effort, for instance by changing the daily used routes or modes of travelling. However, other decisions can enable new travel alternatives and new strategic choices. For instance, moving to a new house or buying a car can strongly change the available choices for the short-term decision making process, and in turn can increase significantly the feeling of satisfaction for the commuting travelling and in general for life welfare.

Our research aim is to gain insight into this complex decision-making process, in order to better understand its relation with transport policy measures.

### 1.1.1 Travel, a derived activity

Except in few cases where the trip is considered as an activity by itself (e.g. riding with a vintage car or experiencing the Trans-Siberian rail trip) individuals value almost exclusively the activity at destination as a benefit (Banister, 2008), while travelling to reach the destination implies a cost. Simply said, economists or mode choice modellers translate this by associating a negative utility to each performed trip.

However, rather recently, authors such as Redmond & Mokhtarian (2001) or Paez & Whalen (2010) report that commuters can associate a positive utility to their home-to-work trip. Of course, this seems counterintuitive because this would indicate that, to a certain extent, commuters would not try to reduce, for instance, their travelling time or their travelling cost. While, so far, the share of "travel likers" (Ory & Mokhtarian, 2005) in the general population remains unknown, such people could be seen as the nightmare of transport planners. Indeed, as indicated by Paez & Whalen (2010) travel likers might be non-responsive to important (and expensive) transport infrastructure modifications such as new rail connection, intermediate metro stops, etc.

Various scientific research works dealing with the ideal commuting time also provide knowledgeable information on travellers' perception of their home-to-work journey. Redmond & Mokhtarian (2001) were among the first to report that the ideal commuting time was not always necessary shorter than the one experienced. Russell and Mokhtarian (2015) using the teleportation concept in transportation research show that not everyone would agree to travel instantly. This indicates that the commuting time can be seen as non-wasted time in some cases.

### 1.1.2 Sustainable mobility in a nutshell

Sustainable mobility can be reached by 1) reducing the need to travel 2) fostering modal shift 3) reducing trips length and finally 4) encouraging greater efficiency in the transportation system (Banister, 2008)

The commuting trip, because of its repetitive pattern both in time and in space, is an excellent target for mobility management measures. Regarding sustainable modal shift, transport policy measures are often aiming at decreasing car attractiveness (push-measures) and increasing public or soft modes attractiveness (pull measures).

Such kind of measures can be implemented at different levels: the supra national, national, regional, local or city level and, of course, the workplace level. Rye (2002) lists the reasons (external regulation, image, parking issues, etc.) that lead institutions to adopt a transport plan and to implement sustainable mobility measures.

Vanoutrive et al. (2010) indicate that, for instance, Brussels, a Belgian metropolitan region, requires a transport plan for private or public institutions hosting more than 200 workers. Due to that kind of regulations the position of transport officer or mobility manager are more and more common (Van Malderen et al., 2013).

The body of literature dealing with the implementation of mobility management measures (or similarly transport policy measures) is now large enough (Rye, 2002; Van Malderen et al., 2012; Gärling and Schuitema, 2007; Graham-Rowe et al., 2011 etc.) and the effect of measures such as a parking policy (see among others Marsden (2006)) or free public transport (e.g. De Witte et al., 2006) is well described.

### 1.1.3 Commuting trip and commuting tours

Workplace, due to the high frequency of the visits and the time spent, is undoubtedly an anchor point for defining the daily travellers' trip chain. Hence, anchor points, such as the workplace or home, are places that structure our activity pattern.

The commuting trip constitutes an ideal target for mobility management measures but not taking into account the complexity of the daily activity pattern where is embedded the home-to-work journey can lead to an overestimation of the positive effect of pull and push mobility measures.

As an example, a conventional staff travel survey focussing on commuting trips might reveal that one individual is commuting by car while living at 500m of her/his workplace, hence being labelled as irrational or not following the widely-adopted principle of *homo oeconomicus*. However, a more in-depth data collection, such as a travel diary, would reveal that everyday this individual is driving a kid requiring special care to an adequate institution. Such striking example shows how analysing a commuting behaviour from two different perspectives (the home-to-work trip vs. the daily activity chain) provides a different understanding of a single choice.

Notwithstanding that the home-to-work trip represents a limited share of the daily mobility, any event (train strike, road accident, etc.) that affects the former will probably affect the latter. While activity chaining (i.e. going from one activity to another without going home, or to another anchor point) is enabling time saving for the individuals, it is also associated with higher levels of car use. As pointed out by Vande Walle et al. (2006), even if the public transport connection between someone's living place and her/his office is good (both in term of frequency and travelling time), the fact that the fitness club he/she planned to go after work is only accessible by car will constrain her/him to use the car on the entire daily pattern. The issue of the "missing link" (Vande Walle et al., 2006) is of tremendous importance regarding sustainable mobility because if a majority of secondary activity places (shopping mall, fitness club, cinemas, etc.) are only accessible by car, this would lead to lower efficiency for transport policy measures that are implemented between major residential areas and the main work centres.

Wang (2015) indicates that in addition to the household time saving due to trip chaining, a reduction of the overall Vehicle-Miles Travelled (VMT) is observed. Regarding the drawbacks of trip chaining, heavier peak hours might be a negative outcome (Wang, 2015) as well as the complexity for public transport coordinator to provide efficient car alternative for activity chain that are gaining in terms of complexity.

### 1.1.4 Workplace relocation: an exogenous life event

As pointed out by the recent work of Schoenduwe et al. (2015) or Rau & Manton (2016), life events are affecting travel behaviour. Graduating from secondary school, obtaining a first job, moving from the parental home are inter-connected events that are sometimes associated with the first car purchase. The use of "Mobility biographies" approach in order to analyse the disruption in travel behaviour that is now popular has been mainly developed by Lanzendorf (2003) and Scheiner (2006).

While having a baby or getting married are life events affecting drastically individuals' travel behaviour (type of activities, activity locations, travelling mode, etc.) these decisions are taken at the households level and thus can be planned accordingly or even postponed. However, some events like a workplace relocation might be exogenous to the individuals and thus not allowing having similar coping strategies.

After a workplace relocation, workers can decide to implement several short and long-term strategies to mitigate possible negative effects (e.g. more time or cost spent on travelling) on their travel behaviour. While route changing for a car user may seem as a low effort adaptation, people already facing "extreme commuting" (Vincent-Geslin and Ravalet, 2016) might opt for longer term strategies such recurrent teleworking, residential move, etc.

## 1.2 Research Objectives

The overarching research objective of this research is **to analyse and quantify the impact in the workers' travel behaviour and activity pattern due to a relocation of their working place**. Two facets of the travel behaviour, which are the commuting pattern and the daily activity pattern, have been covered in this thesis.

Because commuting is an important element shaping the entire daily mobility, it is essential to understand the elements having an impact on the perception that the workers have on their own home-to-work journey. Providing both an analysis of the commuting satisfaction determinants (in the short and on the long run) as well as an analysis of the variation due to workplace decentralization is a secondary objective.

Similarly, understanding how the activity pattern, during working days, is influencing the commuting mode choices is a prerequisite to be able to provide an assessment of the activity space variation related to the workplace relocation.

This thesis also aims at providing some recommendations related to two main aspects. The first one concerns the improvements that can be done in analysing the effect of a workplace relocation. Among other things, we discuss what type of data to collect (cross-sectional survey data, travel diary data, workers' postal code…) in order to reply to which type of research question (analyse short or long-term travel behaviour adaptation). The second line of recommendations is related to the existing ways to mitigate the effect or to improve the possible negative effect of workplace relocation on commuting modal split.

## 1.3 Dissertation organisation

Figure 1 provides an overview of the following chapters of this thesis. While chapters 2 and 3 provide an overview of the literature and a state-of-the-art methodological approach to assess the impact of workplace relocation on commuting mode choice and in general on the decision making of travellers, chapters 4 and 5 focus on the concept of commuting satisfaction and its relation to the utility using cross-sectional survey data. Chapters 6 and 7 analyse more in detail the role of chaining other activities in the home-work tour, and how spatial distribution of these activities changes after workplace relocation. Finally chapter 8 provides the main conclusions and the policy recommendations that can be implemented in relation to the observations done in this thesis.

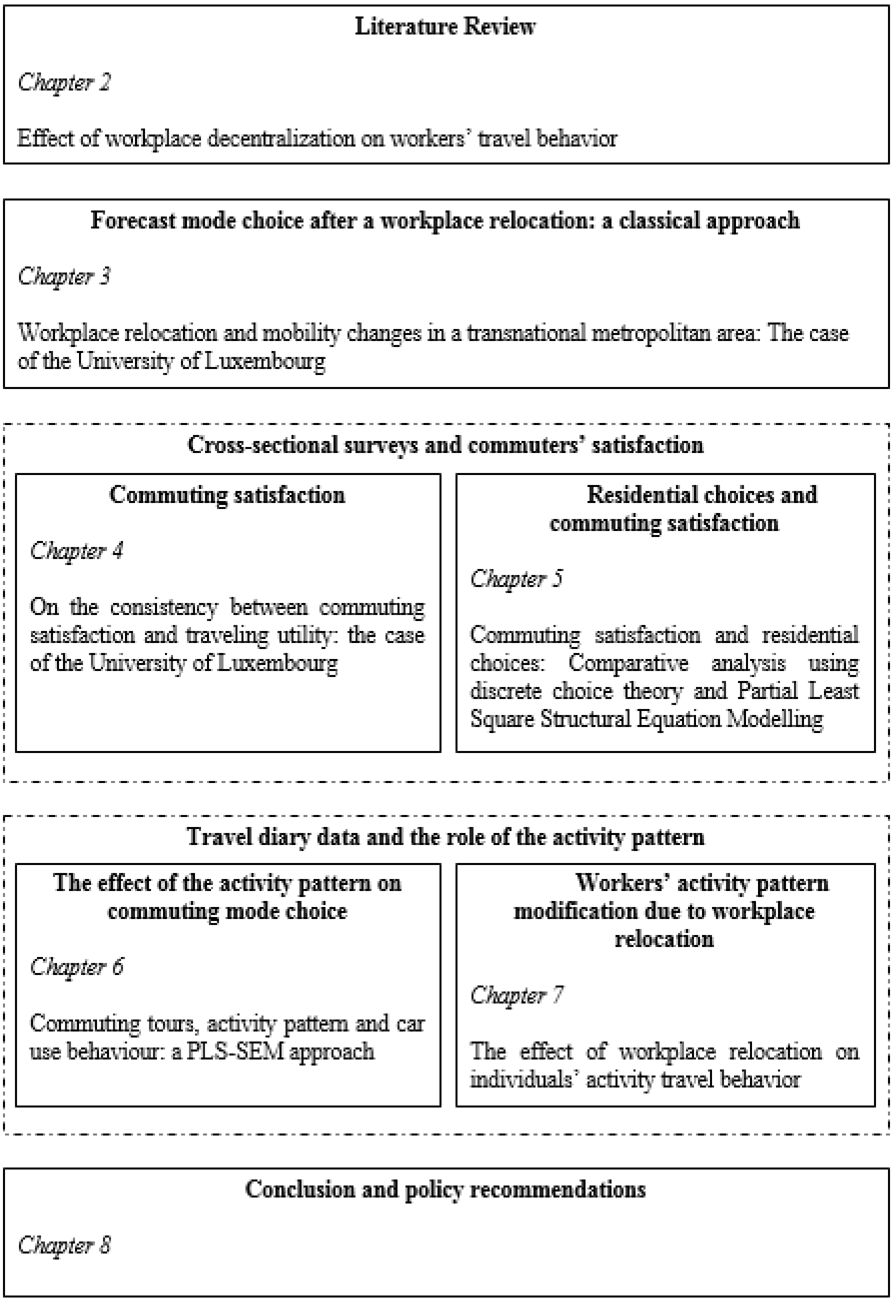


Figure 1 Dissertation organization

### 1.3.1 Literature Review

Chapter 2 provides an in-depth analysis of the impacts of workplace relocation on employees' travel behaviour. The effect of this specific event on the commuting trip (distance, time and mode) is assessed. In addition, short-term (e.g. change mode), mid-term (e.g. adapt activity locations) and long-term (change home location, opt for another job, etc.) strategies that employees can implement in order to mitigate the possible negative effects of the relocation on their travel time budget are discussed. The aim of this section is to provide an accurate overview of the state of the art regarding the issue of workplace relocation and travel behaviour dynamics.

### 1.3.2 Forecast mode choice after a workplace relocation: a classical approach

Chapter 3 proposes an attempt of commuting mode choice forecasting using travel survey data and a Discrete Choice Modelling. The Multinomial Logit (MNL) model used in this chapter constitutes a classical but notwithstanding widely adopted tool to understand commuters' decision and to forecast possible choices using various scenarios.

### 1.3.3 Commuting satisfaction

Chapter 4 investigates the relation between the stated commuting satisfaction and utility (more specifically the Logsum function of the utility). Understanding how people feel about their commuting trip is important because negative feelings might push employees to change (from mode switching to quit their job) their previous routines.

### 1.3.4 Residential choices and commuting satisfaction

Chapter 5 extends the work of chapter 4 by providing an analysis of the effect of residential choices on the stated commuting satisfaction. Thus, the section is dealing both with short-term (mode choice) and long-term decisions (residential choices) of travel behaviour. In addition, this part assesses the effectiveness of using Discrete Choice Models compared to second-generation multivariate data analysis techniques such as Structural Equation Modelling.

### 1.3.5 The effect of the activity pattern on the commuting mode choice

While chapters 3, 4 and 5 were exclusively relying on conventional cross-sectional data (i.e. travel surveys), chapter 6 relies on the use of travel diary data. Using a multi-day data set (51 individuals – 2 weeks of activity pattern encoded) and a Partial Least Square - SEM approach, this section is investigating the relation between the activity pattern during working days and car use. Regarding the development of mobility management measures, the role of the activity pattern of individuals as well as their socio-economic status is discussed.

### 1.3.6 Workers' activity pattern modification due to workplace relocation

Chapter 7 is relying on *ex ante* and an *ex post* workplace relocation using two travel diary data sets. Two weeks of activity-travel information (activity location, duration & type, trip mode & duration) were collected both before and after the relocation of the workplace, i.e. from one campus of the University of Luxembourg to the new campus located in Belval. This unique data set is analysed using GIS techniques (Standard Deviational Ellipses in this case) in order to allow assessing the impact of a workplace decentralization on employees' activity pattern.

### 1.3.7 Conclusions and Policy Recommendations

Finally, chapter 8 is concluding this thesis by taking all the lessons learnt from the previous chapters and put them into perspective. Two sets of recommendations will be provided. The first set of recommendations deals with the possible ways to provide a guideline for researchers aiming at further studying the effect of workplace relocation. The second set of recommendations is related to the measures that can be implemented by large institutions in order to mitigate a hypothetical negative modal shift after a workplace place decentralization.

## 1.4 Contributions

All the chapters (except introduction and conclusion) contain innovative contributions.

*Chapter 2 – Literature review* contains a first comprehensive review of a large number of studies that have investigated the effect of workplace relocation on workers' travel behaviour. Findings are compared, methodologies are discussed, companies' reasons for moving are presented and, most importantly, the knowledge gaps currently missing in the literature are highlighted. To the best of our knowledge this is the first comprehensive literature review focussing on the impact of workplace relocation. At the time of writing, this chapter has been submitted to the Transport Reviews journal.

*Chapter 3 - Forecast mode choice after a workplace relocation: a classical approach* presents an attempt of modal shift forecasting using employees' cross sectional data. Such forecasting exercise is rare and because of recurrent data collection, comparison between scenarios and ground truth is possible. This chapter has been published in the Transportation Research Procedia Series.

*Chapter 4 - Residential choices and commuting satisfaction* presents the first scientific study analysing the magnitude of the discrepancy between commuters' stated satisfaction (a proxy for remembered utility) and the Logsum function of the commuting utility (Decision Utility) with travel survey data. This chapter has been published in the European Journal of Transport and Infrastructure Research.

*Chapter 5 - Residential choices and commuting satisfaction* includes among other things the first comparison attempt between well-known Discrete Choice Theory models and the more recent Structural Equation Model and more specifically the Partial Least Square–SEM. At the time of writing, this chapter has been submitted to Transportation.

*Chapter 6 - The effect of the activity pattern on commuting mode choice* presents one of the very few scientific papers presenting a travel behaviour model using the Partial Least Square Structural Equation Modelling (PLS-SEM) approach. At the time of writing, this chapter has been prepared for (re-)submission to the Journal of Transport Geography.

*Chapter 7 Workers' activity pattern modification due to workplace relocation* is a scientific study relying on a unique data set; two travel diary data sets (before and after relocation) provided by 43 university staff members for 2 weeks. At the time of writing, this chapter has been submitted to the Journal of Transport and Land Use.

## 1.5 The case study

Workplace relocations are specific events and their effect on the activity-travel behaviour still needs to be investigated. Consequently, the relocation of some facilities of the University of Luxembourg constitutes an ideal case study to assess the effect of such life event on the activity-travel behaviour of the concerned employees.

As pointed out by Chilla and Schultz (2014), on March 2003 the government of Luxembourg adopted a policy related to spatial planning. This legally binding policy includes, among other things, a key guiding principle, the decentralized concentration ("décentralisation concentrée"). The main objective of this policy is concentrate urban and infrastructure development in selected communes in order to decrease the pressure (in terms of traffic flows, residential and employment) on Luxembourg City, the capital of the country.

Consequently, in 2005, the Luxembourg Ministry for Higher Education and Research announced that most of the University infrastructures would be consolidated in one single site, Belval. This new town which is located 25km south-west from Luxembourg city has been developed on former industrial land.

Before the relocation, the campuses of the University of Luxembourg were still located in neighbourhoods of Luxembourg-City (Kirchberg and Limpertsberg) or a few kilometres north (Walferdange).

## 1.6 The data collection phases

Different types of data sets have been collected and/or used during this PhD research project. Two different types of data sets can be distinguished, the University staff travel surveys (2012, 2014 and 2016) and the multi-day surveys (2015, 2016). These two types of data have provided different but complementary information regarding the daily mobility of the University staff members.

The first university travel survey has been implemented in 2012 and was seen as a way to provide baseline information regarding the commuting mobility of the University employees. This web survey (Google Forms) developed by the cell for sustainable development of the University with the help of the Geography department also included several questions regarding residential choices. The 2014 and 2016 staff travel surveys were also web-based surveys (developed with Qualtrics) but were shorter and didn't include any question regarding residential choices. Chapter 3 ("Forecast mode choice after a workplace relocation: a classical approach") relies on the 2012 travel survey because, at that time, it was the only data set available. Chapter 4 ("The commuting satisfaction determinants") uses the 2014 travel survey data because the 2016 survey data was not yet available. Chapter 5 ("Residential choices and commuting satisfaction") uses an older data set (the 2012 travel survey) simply because it's the only travel survey data set that includes residential information which was needed for the research question answered in this section. The three travel surveys have been disseminated among the University staff members (including PhD students) via official channels (email from the HR department) ensuring a stable participation rate (around 35%).

The multi day data collection phase has been implemented in June 2015 and June 2016 on a limited number of University staff members. Because Walferdange campus was the first to be relocated to the new campus in Belval, university staff members working there were considered as ideal respondents for the travel diary data collection phase. In April / May 2015, an email asking for participation was sent to all staff members of this campus, 51 individuals accepted to describe 2 weeks of activity-travel behaviour (activity type, location and duration + travel mode and duration). Every-day, respondents were asked to access to a web-platform where they had to encode information of the previous day(s). Appendix A of Chapter 7 presents the structure of the travel diary survey. A monetary incentive (Amazon vouchers) was provided to the respondents to ensure a low dropping rate. The first data collection phase was implemented one month before the move to Belval, the second data collection phase was organized one year after the first one, and thus, 11 months after the relocation. Of course, because one year separates the two surveys, some respondents also faced other life events. Some did not work anymore at the university, some relocated their houses, etc. In order to capture information about a possible modification of their broader life environment a small "life event" survey was implemented. This will be discussed more in detail in chapter7.

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# 2

# Literature Review

The commuting trips represent around one fourth of the workers' total trip but they may affect the employees' entire daily mobility. Together with the home location, the workplace is polarizing the workers' daily activity-travel behaviour. Accordingly, the modification of the workplace location can have serious impact (e.g. in terms of travelling distance) on employees' commuting trips. As response, workers can adopt several short and long-term strategies to cope with such change, and the most obvious are commuting mode shifting or changing residential location. As workplace relocations can be consequence of national policies aimed at decongesting the city centres or to create new business areas, major changes in modal shares and in land developments may be observed. The available literature is now vast enough to discuss about possible trends generalization and to highlight the relevance of context specificities. Regional governments sometimes see workplace decentralization as a way to decrease congestion and companies might see it as a way to get closer to employee's living places. While a decrease in the commuting time after a workplace relocation is, in some cases, observed, an increase in car use for the commuting trip is also often observed. Consequently, this paper aims at providing an in-depth understanding of the effect of workplace relocation on workforce's travel behaviour.

While the relocation of some facilities of the University of Luxembourg was an ideal case study to assess the effect of such life event on the activity-travel behaviour, and specific analysis regarding the modification of the travel behaviour and the activity pattern will be proposed in future sections of this document, this second section is dedicated to a comprehensive literature review. The main objective of this literature review section is to learn from workplace relocations worldwide. Such comprehensive review on the effect of workplace relocation on the travel behaviour will permit to distinguish if the relocation of facilities of the University of Luxembourg is a specific case study or not.

This chapter is based on the paper:

Sprumont F., Viti F. Effect of workplace relocation on workers' travel behaviour: A Survey. Submitted to *Transport Reviews* on 27/10/2017.

## 2.1 Introduction

While the share of commuting trips in the total daily mobility during working days is decreasing, it still represents a fourth of the worker's trips (Cornelis et al., 2012). Due to their spatial and temporal concentration, home-to-work trips are partially responsible of some negative externalities such as traffic congestion and air pollution. For this reason, many transport policy strategies focus on commuting trips, and, in particular, travel demand management (TDM) solutions aim at reducing the number of trips performed by private cars, or to reduce the total distances travelled by car. In this scenario, an effective demand management measure is that of moving firms to different locations, often following a polycentric development plan.

Workplace relocation is an important exogenous life event that has the potential to impact employees' commuting behaviour as well as their entire daily mobility. Since many studies (i.e. Vale, 2013, Yang et al. 2016) indicate that workplace relocations are often associated with a higher car commuting rates, urban planners or policy makers might wish to be monitor and sometimes manage the mobility of firms in order to mitigate or, at least, anticipate possible negative effects. Furthermore, for residential choice, a workplace relocation might need a good transition period to influence commuters towards sustainable transports modes (Bamberg (2006)).

Recently, Rau & Manton (2016) as well as Schoenduwe et al. (2015), have highlighted the effect of such life events on individuals' mobility: residential relocation and a change in the employment status were the two life events having the most impact on travel behaviour. Although these two life events are, in most cases, resulting from individuals' or households' choice, this is not true for workplace relocation, hence some workers have no other choice than to develop adaptation strategies in order to cope with this exogenous event. To cope with office relocation, workers might adopt various short, mid and long term adaptation strategies (Bell ,1991). Shifting to a different mode seems a rather intuitive adaptation reaction, but individuals might also change their job, move their residence to another place, modify their habitual activity locations, modify their activity pattern (e.g. activity sequence, activity duration), acquire or adopt new mobility solutions, etc. (Sprumont et al., 2017).

Vega and Reynolds-Feighan (2009) point out that a strong correlation exists between residential suburbanization (also associated with higher car use level) and the employment decentralization process, as residence and workplace location choice are often jointly determined (Van Ommeren et al., 1996). Thus, a workplace relocation (imposed by the employer) can affect the relationship between the commuting mobility and residential choices.

The effect of workplace relocation on commuting patterns has been studied since the 1960's (Wabe, 1967) and the 1970's (Daniels, 1970; 1972) but this research question has mainly gained popularity in the 2000s (e.g. Aarhus, 2000; Burke et al. 2011, Lee Sim et al., 2011) and is still widely explored (see Li et al., 2016 and Yang et al. 2016 for the latest scientific publications). Geographically, case studies are available for the American continent (Cervero & Wu, 1997, 1998; Cervero & Landis, 1992; Gordon et al., 1989; Gordon et al., 1991), for Europe (Naess & Sandberg, 1996; Hanssen, 1995; Aguilera et al., 2009; Vale, 2013; Aarhus, 2000), Australia (Bell, 1991; Burke et al., 2011; Li et al., 2016) and, finally, Asia (Yang et al., 2016; Sim et al., 2011).

Among the available literature, the terminology used is not always homogeneous. "Workplace relocation" is the most generic term because it does not provide any additional information on the location of the new settlement. "Workplace decentralization" is instead referring to a workplace relocation from a central to a peripheral area, which is not necessarily in close proximity of the city centre or the CBD. The term "job suburbanization" (Cervero & Landis, 1991) is certainly the most specific because it refers to a decentralization process were the new settlement is in the suburb, which is often a lower density area (in term of population and functions).

Efforts have been made to collect and analyse data to gain insight on the impact of workplace relocation on mobility patterns. Some studies (Cervero & Wu, 1998, Aguilera et al., 2009; Gordon et al., 1991; Alpkokin et al., 2008) describe the aggregated effect of employment suburbanization at the regional level using census data. Even if this is unlikely, job suburbanization trends might happen without the relocation of a single company. Creation of a new company in the suburbs, disappearance of business in the city centres might contribute to job sub-centering process. For instance, Aguilera et al., (2009), using the metropolitan travel survey of Paris in 1983 and 1991, showed the effect of job-decentralization without analysing specifically a company relocation. Studies using both approaches, i.e. either the analysis of job suburbanization trends or single relocation events have been included for this literature review. Indeed, it is assumed that single decentralizations are, among other things, the cause of employment suburbanization trends (Cervero & Wu (1998), Aguilera et al. (2009) Gordon et al. (1991)).

The reasons for companies to relocate from a place to another have been rarely discussed. Concerning the advantages of suburban locations, companies might be attracted by more space availability for expansions, lower rental prices and/or the possibility to consolidate different facilities on one site (Bell (1991)). Sprumont et al. (2014) indicated that, for public institutions (the University of Luxembourg in the described case study), the reason could be related to specific governmental spatial planning objectives. Indeed, a workplace decentralization of major institutions can be seen by the national government as an effective way to decrease the mobility pressure on a congested urban area. Already in 1967, Wabe explained how the "The location of Offices Bureau" was fostering companies to move from central London to the periphery. Yang et al. (2016) provided another example of employment decentralization planned by national governmental policies using data from Kunming, China. The impact of massive workplace relocations (or Government Job Resettlement (GJR) using their terminology) from the urban centre to new towns located at the periphery was studied. According to Aarhus (2000) suburban areas become attractive as they may offer faster licensing procedures, planning or construction authorizations and other administrative regulations. Concerning the drawback for institutions for moving from a central to a peripheral site, we can mention the loss of prestige and attractiveness, the possible bigger distance from the "places of power", increased difficulty in reaching the institution's location for visitors, etc.

While this review paper specifically focuses on the modification of the employees' travel behaviour after their workplace relocation, this event might affect the mobility of other people, e.g. recurrent visitors or delivery companies may also adapt their mobility pattern to the new location (Hanssen (1995)). While financial businesses' back office activities might not generate important visitor flows, this aspect might be important for other institutions. As indicated by Naess & Sandberg (1996) when studying the effect of relocation on the energy consumption of employees while traveling, the visitors and freight transport services must be explicitly considered. This review paper also excludes studies analysing the urbanization process for the sake of employment decentralization. Among many others, Giuliano and Small (1991) or Cervero and Wu (1997) have proposed detailed studies of employment sub-centres which are hosting some companies relocating from the city centre.

The first objective of this paper is to provide a comprehensive literature review of the impact of workplace relocation on travel behaviour and to identify possible knowledge gaps. A second normative objective is to provide researchers with advices on which methodology (related to data collection, adapted comparison techniques) should be preferable depending on the investigated research question.

## 2.2 Focus of this review paper

As pointed out by Van Wee and Banister (2016), Literature Review Papers (LRPs) do not always explicitly provide the reason and the selection process of the retained studies. The present study has not been developed as an exhaustive meta-analysis, but more as a comprehensive overview combined with a description of some existing research gaps. The selected papers for this study cover a long period of time (1966 – 2017) and a wide geographical spread (North America, Europe, Asia, Australia). In total, 24 scientific studies were selected and considered for this comprehensive review (see Table 1 for more information). Although the review does not claim to be exhaustive, it is aimed to focus on the most representative studies that provide relevant insight on the impact of workplace relocation on mobility.

Due to an important variety of keywords used to describe workplace relocation (i.e. employment decentralization, jobs suburbanization, offices relocation, etc.) combined with the variety of definitions related to mobility (i.e. travel behaviour, commuting travelling, daily mobility, activity-travel patterns, etc.), it was not possible to use a structured paper selection approach (as suggested by Van Wee and Banister (2016)). A backward snowballing method was used to identify relevant papers. Because English was the language used in the research, studies dedicated to a local audience have probably been overlooked (e.g. in Africa, South America or Asia).

Figure 2 shows the geographical spread of the considered studies, as well as summarizes the main aspects we deemed relevant for this review. In particular, our focus will be on the types of data collected and analysed (e.g., census data collected over multiple years, dedicated travel surveys, …), the study approach (single relocation study, analysis of a larger number of firms, etc.), the methodology adopted for the analysis (quantitative, behavioural, simulation, etc.). Moreover, general conclusions on the impact observed in terms of travel time, distance and mode changes are synthetically summarised.

Some scientific studies deal exclusively with office decentralization but do not include enough information on the mobility aspect to be included in the selected papers. For instance, Daniels (1969), Wabe (1966) or Wright (1967) turn out to be very interesting to understand office decentralization dynamics but do not include information on the commuting behaviour of the concerned employees.

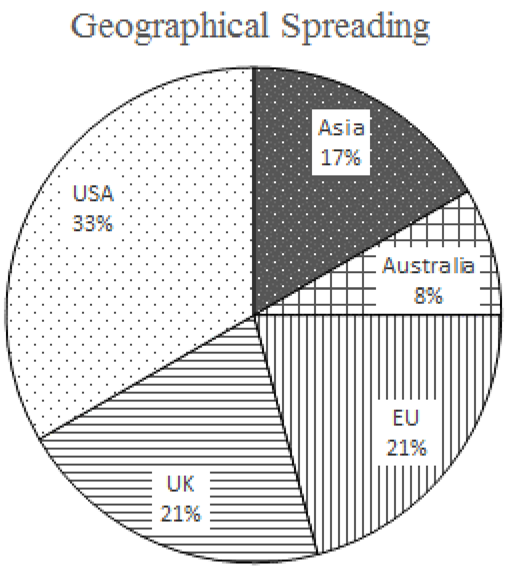


Figure 2 Geographical spreading of the selected studies

| Publications | Spatial context | Type of data | Study approach | Methodology | General conclusion on: Time | Distance | Mode |
|---|---|---|---|---|---|---|---|
| Aarhus (2000) | Oslo, Norway | Post relocation interview with representatives of 5 companies | Single relocation | Qualitative analysis | NA | NA | Car increase |
| Aguiléra et al. (2009) | Paris, France | 1982 & 1999 metropolitan census data + 1983 and 2001 Paris travel surveys | Suburbanization trend | Thorough descriptive comparison | Stable | Slight increase | Slight car use decrease |
| Alpkokin et al. (2008) | Istanbul, Turkey | Workplaces' location in 1985 and 1997 | Decentralization trend | Employment cluster dynamics analysis | Decrease | NA | NA |
| Bell (1991) | Melbourne, Australia | Prior and ex ante travel survey | Single relocation | Thorough descriptive comparison | Decreased | NA | Car increase |
| Burke et al. (2011) | Brisbane, Australia | Regional travel survey, stated preference surveys | Decentralization trend forecasting | Transport modelling & Simulation approach | low decrease | low decrease | PT increase |
| Cervero & Landis (1992) | San-Francisco bay area | Survey on 320 former downtown workers | Suburbanization trend | Submarket analysis and stepwise regression | Decrease | Stable | car increase, PT decrease |
| Cervero & Wu (1998) | San-Francisco bay area | Vehicle miles travelled (VMT) between 1980 and 1990 | Suburbanization trend | Decomposition analysis | NA | increase | Car increase |
| Cervero (1991) | USA | Transportation and land use data at the building level for 6 suburban centres | Suburban centres analysis | Stepwise regression & elasticities analysis | NA | NA | NA |
| Daniels (1970) | Greater London, UK | 1961 and 1966 national employment census data | Decentralization trend | Thorough descriptive comparison | Large decrease | Possible decrease | Car increase |
| Daniels (1972) | Greater London, UK | Survey implemented in 1969 on 63 decentralized offices (7143 respondents) | Several relocations | Thorough descriptive comparison & linear regression | NA | NA | Car increase |
| Daniels (1981) | Greater London, UK | 2 cross-sectional travel surveys (1969 & 1976) implemented on respectively 7143 and 7760 workers) | Several relocations | Thorough descriptive comparison & linear regression | NA | NA | Car increase |
| Gordon et al. (1989) | 25 largest urbanized areas in USA | 1977 and 1983 Nationwide Personal Transportation Study survey | Decentralization trend | Thorough descriptive comparison | Decrease | NA | NA |
| Gordon et al. (1991) | 20 American cities | American Housing Survey data for 1980 and 1985 for the 20 biggest American metropolitan area | Decentralization trend | Aggregated commuting behaviour comparison | Decrease | Decrease | NA |

| Publications | Spatial context | Type of data | Study approach | Methodology | General conclusion on: Time | Distance | Mode |
|---|---|---|---|---|---|---|---|
| Hamilton & Röell (1982) | Cities in USA and Japan | 1972 Annual Housing Survey (USA) and similar info for some Japan Cities | Decentralization trend | Assessment of the monocentric modelling approach | Slight increase | NA | NA |
| Hanssen (1995) | Oslo, Norway | Prior and ex ante one day travel diary | Single relocation | Thorough descriptive comparison | Stable | Increase | car increase, PT decrease |
| Kim (2008) | Seattle area, USA | Household panel data (2 consecutive years) between 1989 and 1997 | Co-location hypothesis testing | Descriptive comparison and location choice modelling | Stable | Stable | NA |
| Levinson & Kumar (1994) | Washington DC, USA | Detailed person travel survey for 1968 and 1988 in Washington DC, USA | Decentralization trend | Thorough descriptive comparison | Stable or slight decrease | Increase | NA |
| Li et al. (2016) | Brisbane, Australia | Traffic volumes | Modelled Single relocation | Transport modelling & Simulation approach | low decrease | low decrease | transit trip increase |
| Naess & Sandberg (1996) | Oslo, Norway | Travel survey of 485 workers from 6 institutions | Single relocation | Multivariate Regression Analysis | NA | Increase | Shift to car |
| Sim et al. (2001) | Tampines, Singapore | Household survey (N=1797), Employees survey (N=439) and Employers survey (N=25) in Tampines area (1998) | Suburban job park assessment | Thorough descriptive comparison | Potential decrease | Potential decrease | Potential car decrease |
| Sprumont et al. (2014) | Luxembourg, Luxembourg | Travel survey before the relocation (329 replies) | Modelled Single relocation | Discrete Choice Models | Slight increase | Increase | Shift to car |
| Sprumont et al. (2017) | Luxembourg, Luxembourg | 2 weeks travel diary before and after (51 individuals) | Single relocation | Standard Deviational Ellipses | NA | NA | NA |
| Vale (2013) | Lisbon, Portugal | Retrospective questionnaire | Single relocation | Discrete Choice Models | Slight increase | Slight increase | Car increase |
| Walker et al. (2014) | Godalming, UK | 3 Surveys (1 before, 2 after) common in psychology to assess employees' mode habits | Single relocation | Linear mixed-effects model and logistic regression | NA | NA | Train increase, car decrease |
| Wabe (1967) | London, UK | Questionnaire on a firm workforce (600 staff) 2 years after the relocation | Single relocation | Thorough descriptive comparison | Important decrease | Possible decrease | Car increase |
| Yang et al. (2016) | Kunming, China | Stated Preference + Revealed Preference survey | Single relocation | Discrete Choice Models (MNL) | NA | NA | From soft and PT to car use |

NA: Not addressed

Table 1 Selected papers

## 2.3 Data collection and methodological approaches

### 2.3.1 Data collection strategy

The research questions addressed in the various scientific studies selected in this review paper suggest the collection and analysis of different types of data. Some studies such as Aguilera et al. (2009) or Cervero & Wu (1997) have studied workplace decentralization as long-term trend without focusing on describing a single workplace relocation like Vale (2013) or Bell (1991), etc.

Analysing job suburbanization trends on relatively broad geographical areas require, first, to have comparable databases collected at two or more survey periods with the right time in between. Cervero & Wu (1998) have used data (size and density) from employment centres in the San-Francisco Bay Area in both 1980 and 1990 to generate and then analyse journey-to-work statistics. Similarly, in order to analyse the workplace location dynamics in Istanbul, Alpkokin et al. (2008) have used employment data in 1985 and 1997, while Gordon et al. (1991) have used data from the American Housing Survey of 1980 and 1985 for the twenty largest American metropolitan areas, hence providing general analyses at a nationwide level.

In order to study office decentralization at the workplace level, many authors such as Cervero & Landis (1992), Aarhus (2000), Hanssen (1995), Naes & Sandberg (1996) have used a wide range of different data collection approaches. Bell (1991) used *prior* and *ex-ante* cross sectional surveys to assess the impact of a workplace decentralization in Tooronga, Australia. Cervero & Landis (1991) have identified and selected workers whose jobs had been relocated from downtown San-Francisco to the suburb and asked retrospective question about their travel behaviour after the relocation and question about their behaviour after the move. Similarly, to Bell (1991), Hanssen (1995) collected travel behaviour information before and after the event but instead of implementing a classical travel survey opted for a one-day travel diary.

An important time interval between two data sets allows to observe long-term effects of a relocation, but ongoing general trends might also affect the assessment of the firm relocation (Daniels (1970;1972;1981); Wabe (1967)). Daniels (1972; 1981) explains that while significant increases in car ownership rates 8 years after companies decentralization were observed, this is probably associated to general car ownership trends in the UK during the 1960's and the 1970's. Levinson and Kumar (1994) who used travel survey data of 1968 and 1988 mention that this rather long period was also characterized by "Metropolitan trends" (car ownership increase, population and travel demand increase, etc.) and also by important transportation infrastructure developments.

Depending on the time interval, implementing a data collection phase before and after the relocation can lead to response rate issues. Bell (1991) implemented the ex-ante survey 5 months before the relocation and the second survey was implemented 10 months after the relocation (15 months' time between prior and ex ante surveys). In this study, constituted of 846 valid replies, 50% of respondents was in common if compared to the first wave. As pointed out by Sprumont et al. (2017), a long time gap between the before and after data collection might have several drawbacks. First, some workers may have meanwhile decided to quit their job, other might have decided to relocate their house or other anchor activities (children's school location, preferred shopping places, …). These mid and long-term adaptations might interact with short-term adaptations. Daniels (1972 & 1981) performed a data collection campaign 8 years after implementing a first survey. It turned out that only 27% of the workers who participated to the first data collection phase also took part to the second phase. In addition, some employee's company did not understand how they could contribute to the survey since they had been recruited years after the settlement of the firm to that actual location (Daniels (1981)). Wabe (1967) also faced issues while collecting data from a firm (600 employees in total) two years after it moved from the London CBD to the suburbs. Indeed, no information was available regarding the share of workers who had quit the company in the meantime. Assessing the effect of workplace relocation after a long time interval might be tricky in the sense that some firms might not consider themselves as decentralized (Daniels, 1981).

The adopted data collection method is an equally important aspect if compared to the number and frequency of times the data is collected. Stated preference is a classical method to obtain information on travel behaviour changes (mode choice, change in individuals' socio-demographic characteristics, etc.) Yang et al. (2016) have used stated preference surveys to assess the impact of Government Job Relocation (GJR) in Kunming, China. They acknowledged the possibility that respondents, when filling the stated preferences experiment, may have chosen hypothetical travel modes without realizing all the implications for the data analysis (travel time, access to public transport services, etc.). Aarhus (2000), who opted instead for a focus group analysis, interviewed representatives of 5 companies in Oslo (Norway). This approach provided valuable information about the determinants of location selection of relocating companies, but did not provide precise information on modal split variations, commuting times or distance increases, etc. Walker et al. (2014), when studying the relocation of a pro-environmental charity (WWF) in the United Kingdom, adopted a very interesting strategy, which consisted on collecting information 19 months *prior* to the relocation and then 1 and 4 weeks after the move. This very peculiar data collection was implemented in order to test behavioural attitudes related to travel mode selection. Specific data were collected such as the Environmental Attitude Inventory (EAI) and a Self-Report Habit Index (SRHI). Sprumont et al. (2017) have also developed and implemented a similar sophisticated data gathering process. One month and one year after the relocation, they implemented a travel diary data set on 51 employees. For 2 weeks (including weekends) respondents provided information on all their activities (location, activity type, duration) and trips (time, mode), hence giving useful information on complete activity-travel chains. In addition, a stated preference survey was also collected using the same individuals to enrich the dataset with socio-demographic and other travel behaviour-related data.

Obviously, the data collection strategy depends on the research question and has to be developed carefully. Assessing the impact of an event, workplace relocation in this case, means that sufficient data collected both before and after the event will be needed, which causes additional complexity in the research process. Asking retrospective questions about travel behaviour before a workplace relocation combined with questions regarding the behaviour after the move seems good trade-off between data quality and time investment. Depending on the timing of the data collection phase, results provided by retrospective questions might be distorted by time. This issue was already raised by Wabe (1967), who highlighted that when asking for the commuting time at the previous workplace some inaccuracies might arise.

### 2.3.2 Methodology

Similarly to the data collection approach, the selected methodology varies importantly according to the research question. Older studies such as Wabe (1967), Daniels (1970, 1972, 1982) or Bell (1991) rely more on thorough descriptive analysis of both before- and after-relocation situations. As alternative, travel behaviour modelling can exploit the data and provides prediction opportunities. Yang et al. (2016) used discrete choice models (Multinomial Logit) with revealed and stated preference data to compare the variation of parameter estimates between anticipated and actual mode choice. With limited data (travel survey prior to the workplace relocation), Sprumont et al. (2014) also used a Multinomial Logit (MNL) model to forecast the future modal shifts at the new workplace. Similarly, but at a larger scale, Li et al. (2016) and Burke (2011) compared different decentralization scenarios for 2031 at the city level using strategic transport modelling to estimate aggregated modal shares, vehicle kilometres travelled and vehicle hours travelled. This long-term forecasting approach is particularly interesting to analyse and test various policy regulations to mitigate the possible drawbacks of workplace decentralization.

In order to analyse workplace decentralization trends in Istanbul, Alpkokin et al. (2008) used employment dynamic clustering analysis. The methodology they developed can be reproduced and compared to Istanbul, their case study. Walker et al. (2015) applied an established methodology from psychology to analyse travel habit formations and decays during workplace relocation. They used data from Environmental Attitude Inventory (EAI) and a Self-Report Habit Index (SRHI) to develop a linear mixed-effects model to compare habits strength for the new and old mode and logistic regression to predict travel mode change. In order to assess the employees' activity space variation after a workplace relocation, Sprumont et al. (2017) used Geographical Information System (GIS) tools and more specifically the Standard Deviational Ellipses (SDE) to assess the variation of the activity space related to a disruptive event in the activity-travel routine such as a workplace relocation. Notably, this approach allowed to gain additional insight into the impact of relocation to the whole daily and weekly activity-travel behaviour of the employees.

Obviously, no methodology is claimed to be better than others and, often, several methodologies may be applied to common datasets. The scientist's research question will guide him or her towards a specific methodology which will probably influence the data collection phase (if a data collection phase has to be done). A narrow, very specific research question can lead to specific data gathering processes and less conventional methodological approaches (Walker et al., 2015; Sprumont et al., 2017). Studies covering most of the aspects of commuting pattern modification (commuting mode, distance and time) due to workplace relocation were also mostly relying on thorough descriptive analyses (Wabe,1967; Daniels, 1970; 1972; 1982 or Bell, 1991).

## 2.4 Short term impact of workplace relocation

### 2.4.1 Workplace relocation and commuting behavior

Modal shifts related to workplace relocation can be due to modifications of 1) the Public Transport (PT) accessibility 2) the road accessibility 3) the parking provision and 4) the share of employees with a short distance to work (Aarhus (2000)). Of course, a relocation from the city centre to the suburbs has the potential to affect all of the aforementioned 4 elements. According to Naes & Sandberg (1996), the modal split variation is partially due to a modification of the distance to the CBD and the density of the local area.

Regarding mode choice, Bell (1991) shows that after a decentralization from Melbourne city centre to a suburban area 8.5km away from the CBD car use increased from 34% to 76%. Hansen (1995), using data from Oslo, indicates that the suburbanization of an insurance company increased car use from 25 to 41% despite that the new worksite was well served by public transport. More striking modal shift observations were provided by Wabe (1967) who indicated that a firm decentralization in London led to an increase in car use from 8% to 71%. However, as pointed out recently by Yang et al. (2016), the relocation of the employees is not *per se* leading to higher car use.

Often, people tend to stick to a commuting mode they are familiar with, as long as the commuting time remains below an acceptable threshold, hence showing mode selection habits (Vale, 2013). This travel mode inertia explains why, using data from Lisbon (Portugal), 73.3% of employees facing an office decentralization did not opt for a new commuting mean of transport. In order to keep (or achieve) important share of public transport users after a relocation, the provision of good transit service at the new location is a must. However, Transit Oriented Development (TOD) with good public transport provision is not guaranteed to lead to lower share of car use among the commuters (Hanssen (1995)). Due to cheap land availability, the provision of free parking spots is often a reality in suburban working sites and the better road conditions play a role as well. Indeed, compared to the CBD, suburban locations often enjoyed a less congested road network. Free parking and good road accessibility are also important car incentives. Cervero (1991) confirmed that, at least for the American context, suburban areas are also associated with free parking (because of cheap land availability) and poor public transport connections. Hanssen (1995) showed that after a company move from the centre to the suburb share of public transport users having to make one or more transfers increase of 20% (from 8 to 28%). The employment suburbanization is sometimes leading to a less favourable public transport accessibility.

Interestingly, Walker et al. (2014) found that travel habits weakened immediately after a workplace relocation regardless if the employees shift to a new mode or not. Habits of workers who opted for a new mode did not disappear brutally but slowly decayed after the post-move period and during a period of 4 weeks. A disruptive event such as a workplace relocation is hence a good opportunity to foster modal shift but according to Walker et al. (2014) this “window of opportunity for change” can also be seen as a ”window of vulnerability to relapse”. After a workplace decentralization Bell (1991) observed that car started to be seen as a “faster, more reliable, less expensive, more comfortable, cleaner and more convenient” commuting mode. If a certain share of workers shifts from, for instance, public transport to car, this could partly explain why, in some job decentralization studies, the commuting distance increase but the commuting time remains roughly constant (Vale, 2013).

Employment decentralization was during the 1980s the dominant spatial trend in American metropolitan areas (Cervero & Wu (1998)). Due to the enormous possible impact on travel behaviour, numerous studies were undertaken to understand the aggregated effect on commuting time, distance and mode. The co-location concept, developed by Gordon et al. (1989) posits that companies were selecting suburban locations in order to locate themselves closer to their employees, who had slowly moved to the suburb. Kim (2008) provided an interesting study on the effect of co-location on commuting time stability and mentions that “little evidence contradicts the co-location hypothesis”. Despite a probable shortening of the commuting time, the overall environmental impact appears to be dramatic. Indeed, despite the intense debate on the co-location hypothesis (see Kim, 2008) regarding the commuting time or distance there is little doubt regarding the significant car use increase. Levinson and Kumar (1994) or Gordon et al. (1991) also underlined the fact that dispersed or polycentric metropolitan structures are associated with shorter commuting times.

Regarding the commuting time, Wabe (1967), in the London area, indicated that after a company suburbanization, the average commuting time of employees was halved. The good road conditions and the massive shift towards car use are an explanation for this important commuting time decrease (Hanssen (1995)). Similarly, as observed in the Australian context, (Li et al., 2016; Burke el al., 2011) the decrease in the home-to-work time would be partially due to the non-congested road network state for reverse commuting (from the centre to the suburbs). Cervero & Landis (1992) proposed interesting workers submarket analysis and indicate that if the aggregated commuting time was decreasing due to switch to faster mode and stable commuting distance this situation was not verified for all types of residential areas. In analogy to Aguilera et al. (2009), Cervero & Landis (1992) showed that, for instance, reverse commuters (e.g. downtown resident whose new workplace is in the suburbs) were facing an important increase of their commuting time and distance.

Many studies have shown that relocation or decentralization of firms was often associated with high car use levels (Wabe, 1967; Bell. 1991, Daniels, 1970; 1972. 1981). However, counter examples can be find e.g. in the studies from Walker et al. (2014) and Sim et al. (2001), who mention a (possible) modal shift towards sustainable alternatives (mainly, from car to PT). Due to the very large and complex body of available literature, the question related to the relation between workplace relocation and urban forms (monocentric, polycentric, scattered, etc.) has only been superficially covered in this paper. Sim et al. (2001) or Gordon et al. (1991) for instance constitute an entry door to this complex question.

### 2.4.2 Activity pattern modification & change in the daily mobility

Workplace decentralizations are affecting the commuting trip characteristics (road & PT accessibility, parking provision, commuting distance) (Aarhus, 2000) and when the home-work-home trip is routinized, the entire daily activity pattern is also affected. Aguilera et al. (2009) showed that job suburbanization was associated with a decrease in the number of daily journeys performed by working central city residents. Bell (1991) showed that a workplace to an isolated new site can have important impact on the daily activities performed. In total, the workplace relocation led to a 10% decrease in the number of activities performed during a day (from 2.2 to 2 activities). The modification of the activity pattern is the example of a short-term adaptation due to a workplace decentralization. Bell (1991) shows that the number of shopping activities performed per day decreased from 23.8% to 15.2%.

More recently, Sprumont et al. (2017) have shown that after a workplace relocation the activity space of 51 individuals had spatially completely changed. It is not only the workplace activity that move from one place to another but most of the activity places that were visited close to the former working site. Sprumont et al. (2017) concluded that the national objective which was to decrease pressure (in terms of trip mainly) from Luxembourg city is achieved because only very few respondents still have activities close to their former working place.

## 2.5 Long term impact of workplace relocation

### 2.5.1 Car ownership

The increases in car ownership due to a workplace relocation or a job decentralization have rarely been the main focus of research studies. Notwithstanding, each time it has been analysed, the workplace relocation has been associated with higher car ownership. However, the low number of studies and, sometimes, long time interval affected by existing ongoing national trends (Levinson and Kumar, 1994) do not allow any generalization.

In 1991, Bell, analysing the relocation of a major company in Melbourne (Australia), observed an increase in car possession after the decentralization of the workplace. Indeed, a decrease (from 28,9% to 24,8%) of households owning only one car was reported, and the post relocation travel survey revealed that 8.2% of the respondents bought a car because of the new work location. Hanssen (1995) reported how in a Norwegian held study (Plandirektoratet, 1990) an increase of car possession of 10% was measured among the employees, after a workplace decentralization of 20km.

Regarding car ownership variation after companies relocation, Daniels (1972; 1981) observed that, while between 1969 and 1976 household car ownership of employees at decentralized office increased from 72.4% to 79.7%, this was possibly more related to a general ongoing trend rather than a direct effect of the workplace decentralization. Levinson and Kumar (1994), when analysing the impact of the job decentralization pattern in Washington DC between 1968 and 1988, also faced similar issues. Indeed, for this specific area the number of cars per person increased from 0.48 to 0.73 and household car ownership increased from 1.6 to 2.0.

### 2.5.2 Residential choices

While residential relocation due to a suburbanization of the working location is assumed to be a rather long-term decision, Bell (1991) indicated that 10 months after a workplace relocation 15.4% of respondents to the prior survey indicated a change of residence, however, only 2% claimed that this decision was directly related to the new workplace location. Ten months after the move, Bell (1991) observed a modification of the spatial pattern of the employees' living place.

As mentioned by Naes and Sandberg (1996) using data from Olso, Norway, in the long term residential changes among the employees and staff turnover didn't balance the immediate increase in home-to-work distances due to the workplace relocation.

Hanssen (1995) collected a one day travel diary before and after the workplace relocation and did not find important changes in the residential location of the employees. As opposed to Bell (1991), it is possible that Hanssen (1995) did not find any residential relocation trend because of the small distance between the old and the new workplace (the study considered a 6 km relocation between the old and the new workplace, for a major insurance company counting 1200 employees).

According to the co-location hypothesis (Gordon et al. 1989;1991, Levinson and Kumar, 1994 or Kim, 2008) the average commuting time has either remained constant or decreased in large American cities since the 1970',s due to a location adjustment of both firms and households. Gordon et al. (1991) mentioned that both firms and households moving towards suburban areas "do a very nice job of achieving balance, and keeping commuting times within tolerable limits without costly planning interventions". Cervero & Landis (1992) showed that workers whose employment has been relocated to the suburbs might decide to follow their job and relocate their house.

### 2.5.3 Workforce Turnover

When working with prior and ex-ante workplace relocation cross-sectional surveys, differences in aggregated modal split are presented (e.g. Bell, 1991). However, by using this data collection approach, information on workers whose contract ceased between the two data collection phases is unknown.

Daniels, who implemented 2 distinct studies (1972 & 1981) with 8 years of interval, indicated that only 27% of the employees who participated to the first data collection phase also took part to the second phase. So far, little is known regarding the magnitude and the reasons for this behaviour. Of course, some natural reasons without link to the relocation (contract ending before the relocation, better job opportunity) might explain some departures. This is roughly in line with Kim (2008) who indicated that in many European and US cities, annually, approximately 20% of employed workers changed workplaces within the same metropolitan area.

Bell (1991) indicated that some workers, because of a particular lifestyle or specific mode choice attitude (see De Vos et al. 2012), may prefer a job-position downtown (or oppositely in the suburbs). Then, a workplace suburbanization might affect workers differently because of their mode preferences or lifestyle. While a workplace relocation can be related to higher car use levels among the concerned workforce, new hired employees (possibly locally to the new worksite) could have different modal split statistics with lower car use level (Hanssen (1995)). However, Daniels (1972; 1981) contradicts this assumption and highlights that staff replacement and new recruits did not lead to lower car use levels even 8 years after the company relocation. Already in the 1960s, Wabe (1967) raised an important issue regarding the employees' status and their adaptation regarding the company relocation. Consultants, who can represent an important share in engineering or IT companies, might be totally neglected by studies analysing the effect of workplace relocation on firms' workforce. Firstly, consultants or sub-contractors may not be considered in the data collection phase targeting the company employees. Secondly, these specific worker categories often have complex residential and commuting mobility patterns due to the specificity of their position.

## 2.6 Implications of workplace relocation at the regional level

While the impact of a workplace relocation may lead to a shift from public transport mode to a private one, concluding that the new worksite leads to a less sustainable mobility behaviour appears short-sighted. Indeed, due to mode choice inertia (Vale, 2013), the "movers" might continue or start to use car to keep that travel time acceptable but the "new comers" might have a different modal split.

Yang et al. (2016), using stated preference surveys, developed a methodology that could be applied by transport planners to assess the impact of workplace decentralization on the transport demand characteristics. However, modelling results from Yang et al. (2016) have shown important differences between anticipated and actual model choice. This was confirmed in other forecasting studies (Yang et al., 2016 or Sprumont et al., 2014), hence long-term predictions in case of workplace relocation should be considered with caution.

Cervero & Landis (1992) indicated that while workers who relocate might be better off because of faster commuting and the use of "superior form of transportation" (car) the social and environmental impact might be negative. Indeed, Naes & Sandberg (1996) confirm that even in case of stable commuting distance after an office relocation, the energy needed by the employees to reach their new worksite is significantly bigger.

Concerning policy recommendations, Cervero (1991) provided interesting research directions to mitigate a possible modal shift towards car. Indeed, he reported that building single-tenancy is associated with van pool and carpool to work. Building density also seems to matter, because a 10-storey decentralized office will exhibit a 4% higher transit use compared to a 1-storey building. Thus, clearly, when developing decentralized office centres, planners should keep in mind that a bigger suburban project with high and mixed-use buildings will positively affect public transport use. When developing suburban office centres, size counts (Cervero, 1991).

While Hanssen (1995) and Wabe (1967) indicated that workplace decentralization was leading to shorter commuting time partly because of a less congested road network, an increasing number of firms moving to specific sub-centres may badly affect the local network. On the other side, decentralization by moving company location from the centre to the periphery might decrease crowding in public transport lines directed towards the city-centre, to the advantage of workers commuting therein.

## 2.7 Discussion and conclusion

Many, but not all considered scientific studies have underlined an increase in the share of car commuters after work place decentralization. However, as pointed out by Yang et al. (2016), there is no causal relation, workplace relocations do not lead *ipso facto* to higher car use among workers. Sim et al. (2001) conclude that in Singapore, a place exhibiting high reliability public transport services, workplace relocations have the potential to lead to lower car use for commuting trips. Walker et al. (2015) have also shown that car use increase after a workplace relocation is not automatically leading to higher share of private vehicle use for the home-to-work trip.

Aggregated modal split differentials are mainly due to variation of the relative public transport and road network accessibility, the change in parking management schemes and the share of workers living within short distances (Aarhus, 2000). In other words, as shown by Naes and Sandberg (1996) when assessing the impact of workplace relocation on the commuting behaviour, the contexts of both the old and the new workplace are crucial.

While a relocation can have a detrimental effect on the commuting mobility (in terms of $CO^2$ emissions, for instance) it does not mean that the new working place location is unsustainable regarding transportation. A workplace relocation from the city CBD to a peripheral Transit Oriented Development (TOD) area will certainly generate an unsustainable modal shift from the movers, while the aggregated modal share of the newcomers might be virtuous. Such trend has never been reported in the scientific literature but it's expected that on the very long run the aggregated modal split will stabilize to the modal split of the new-comers employees.

Without any national or regional policy regarding suburban parking regulations or voluntary sustainable transport strategy, car use will remain an over-attractive commuting alternative. Free parking lots, uncongested (or barely congested) suburban networks will still push workers to use private motorized modes of transportation despite efficient public transport services. Cervero (1991) provided an interesting example with 2 major companies located closeby. The first company provides a non-free parking lot to 34% of its workers and the second one has 730 free-spaces for 650 workers. While at the first company, 35% of the workers carpool and 12% come by transit, only 8% of the employees of the second company carpool and 85% drive alone.

As pointed out by Vale (2013), mode choice inertia will lead workers to stay with the mode they were using prior to the workplace relocation as long as there is no major commuting time increase. Thus, in order to anticipate commuting mode shift due to an office suburbanization, the modal split before the relocation is an acceptable benchmark value. However, as pointed out by Walker et al. (2014), the workplace relocation can be considered as a discontinuity in the habitual commuting pattern and thus can potentially be a good opportunity to push away workers from Single Occupant Vehicles. Thus, depending on the involvement level of the different parties (Regional authorities, City government, private and public institutions), whether a specific planning policy or a "laissez-faire" approach is implemented in terms of travel behaviour - more specifically car use - workplace relocations could be seen at the same time as a potential threat or an unexpected opportunity.

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# 3

# Forecast mode choice after a workplace relocation: a classical approach

From the previous chapter, it becomes clear that the relocation faced by the University of Luxembourg is not an exceptional event that has already been faced by many institutions (public or private) worldwide and studied in different aspects. However, a gap highlighted in the literature review is that the impact of this event on mode choice, especially considering the complexity of the daily activity-travel chain of the employees has been overlooked. Travel behaviour analysis in this problem is complex because of the many determinants that can influence decisions' makers and disruptive event such as a workplace relocation can influence all decisions regarding the activity pattern and the associated trips.

The aim of this chapter is to study the utility variation related to the commuting mobility of University staff members due to their future workplace relocation. During the year 2012, a travel survey was completed by a total of 397 staff members, representing 36.4% of the university employees, who filled in a questionnaire which revealed complex decision-making patterns due to the special traveling scenario involving four countries at once. This 2012 staff travel survey is the first of its kind at the University of Luxembourg and the collected data will serve as a benchmark.

A Multinomial Logit model has been used to anticipate the impact of university relocation from the capital city to a developing area in the south of the country which will happen between 2015 and 2018 and that will affect most of the employees. Of course, when developing a Multinomial Logit model, travel survey data is essential to obtain the model parameters estimates. While the data provided by decisions makers as well as the data collection phase are often well described in scientific studies some other steps in the modelling process are less straightforward. Generally, the trip information (time, distance, cost, comfort, etc.) regarding the chosen alternative is collected thanks to the survey, but collecting information on the non-chosen alternative is responsibility of the researcher. Depending on the number of alternatives defined (Car, Public Transport and soft modes in this case), the complexity of the transport network and the assumptions that are made the time necessary do gather the necessary information can vary a lot.

This methodological parenthesis regarding the data collection process shows that, while results of modelling approaches are necessary to understand complex processes, they also constitute a simplification of a more complex reality. This thesis completes this study with also a comparison between modal choice forecast obtained using a Multinomial Logit and data collected recently. Doing this assessment permit to partially understand why modal choice forecast and traveller's decisions differ.

Finally, the effects of several Travel Demand Management measures are discussed based on the analysis of alternative scenarios.

This chapter is based on the paper:

Sprumont F., Viti F., Caruso G., König A. (2014). Workplace Relocation and Mobility Changes in a Transnational Metropolitan Area: The Case of the University of Luxembourg. *Transportation Research Procedia*, 4, 286-299.

## 3.1 Introduction

Due to population increase and the multiplication of activities undertaken by people, mobility has rapidly become a crucial topic. Most work-related or leisure activities require to travel between locations. Travel is therefore a derived activity, thus, the transport mode chosen has, to some extent, to minimize the time needed to reach the selected activity location. In the second half of the 20th century, political choices were taken to improve the infrastructure system to travel by car. However, over-reliance on cars for individual travel carries important social and environmental costs, including emissions of pollutants and greenhouse gases, construction and maintenance of dense road networks, provision of parking space, time loss in traffic congestion, negative externalities on health, etc. There is wide agreement about the negative effects of car-dependence for regions and cities (e.g. Kenworthy (2006), Dupuy (1999)) and the necessity for developing a more sustainable system (Costanza and Pattern (1995)).

The main aim of this research is to better understand which factors affect the utility variation related to the commuting mobility when major changes influence the commuting patterns of a large community, and how this understanding can help us at developing effective measures to incentivize sustainable mobility behavior. To pursue this goal, we focus in this paper on analyzing the behavior of the staff members of the University of Luxembourg due to their work place relocation. The objective is also to provide evidence on the possible impacts of some Travel Demand Management (TDM) measures. Conclusion of this study might be taken into account to discuss the implementation of sustainable transport measures.

As destination of the commuting trips any public and private organizations should be concerned with sustainable transport (Van Malderen et al. (2009), Vanoutrive et al. (2010)). In this respect, universities, it can be argued, have a pivotal role to play in fostering social and technological innovation for sustainable development, through research, education and civic engagement. Within this important role, special effort should be made to meet, if not exceed, the ambitious modal split targets set by Luxembourg public policy.

## 3.2 Context

### 3.2.1 The commuting mobility in Luxembourg

Within the mobility system, commuting to work is one of the most important aspects. Commuting accounts for about 25% of households' travel (OECD (2001)).

Every day the Grand-Duchy of Luxembourg has to cope with a demand of over 160 000 cross-border workers (STATEC (2014)) representing 44 % of the total work force in the country. Among these cross-border workers, 89 % use only the car for their home-to-work trips while this figure reaches 76 % for the residents (Carpentier and Gerber (2009)). The share of public transport users is rather low compared to the high quality of the infrastructure (Klein (2010)) but this has to be balanced by, among other things, the important highway density and the positive car image in Luxembourg (Epstein (2010)).

This huge difference in terms of travel mode choice between cross-border and resident users for commuting is mainly due to travel distances. Residents have a median home-to-work distance of 12km when this figure reaches 40km for cross-border workers (Carpentier and Gerber (2009)). Such long distances are not always compatible with public transport use and nearly never with active transportation modes. In addition, there is a lack in the integration of public transport systems between countries, both in terms of service scheduling and coverage, and in terms of pricing. Extra costs are in fact included in, for instance, train fares when crossing the border, making a trip by train relatively expensive.

However, ambitious modal split targets have been set by the government (the national 2020 target is 25% of total trips by low-impact modes and 25% of motorized trip by public transport). Stronger transport objectives in term of modal split have been set for the city of Esch/Belval, a developing activity pole location in the south of the country at about 25km from the capital, where the University will relocate most of its infrastructures. The aim is to obtain a share of 40% of the total trips done with the public transport system (and keep the same objective for low impact modes).

This is clearly unachievable if measures are not taken that consider the difference between national and transnational mobility requirements and constraints.

In Luxembourg, the public transport coverage reaches 95% of the total locality and 75% of the total jobs in the country (Klein (2010)). The good coverage and the frequencies are compatible with home-to-work or home-to-school trips. The description of the public transport system may seem idyllic but, in the same time, road infrastructure in Luxembourg is one of the most developed in Europe. The country has the third denser motorway network (km of motorway divided by the total surface of the country) and the first ranked for the number of motorway km per inhabitants (Epstein (2010)).

### 3.2.2 The university of Luxembourg

With more than 1200 staff members and 6200 students (October 2012), the University of Luxembourg is a relatively large institution in the Luxembourg context and thus an important trip generator/attractor. Currently, the university infrastructures are mainly located on three different campuses namely Campus Limpertsberg, Campus Kirchberg and Campus Walferdange. These three campuses have different accessibility levels but are all three located in or around Luxembourg-city which has developed in the last years as a strong monocentric activity pole. The dramatic increase of traffic issues due to this development has suggested the government to relocate different activities to other areas, in particular in the south of the country which has still enormous potential for development.

In the near future the majority of the University of Luxembourg will move to Belval (located in the municipality of Esch-sur-Alzette). This “New-town” will gather most of the Public Research Centers of Luxembourg. This urban development project on industrial wasteland undertaken by the government is seen to contribute to decrease the current pressure (in terms of commuting flows, residential prices...) on the city of Luxembourg, which currently concentrates about 51% of all work places. This strategy is known as the “decentralized concentration” and is promoting a polycentric development to balance the over-growing pole of Luxembourg-City.

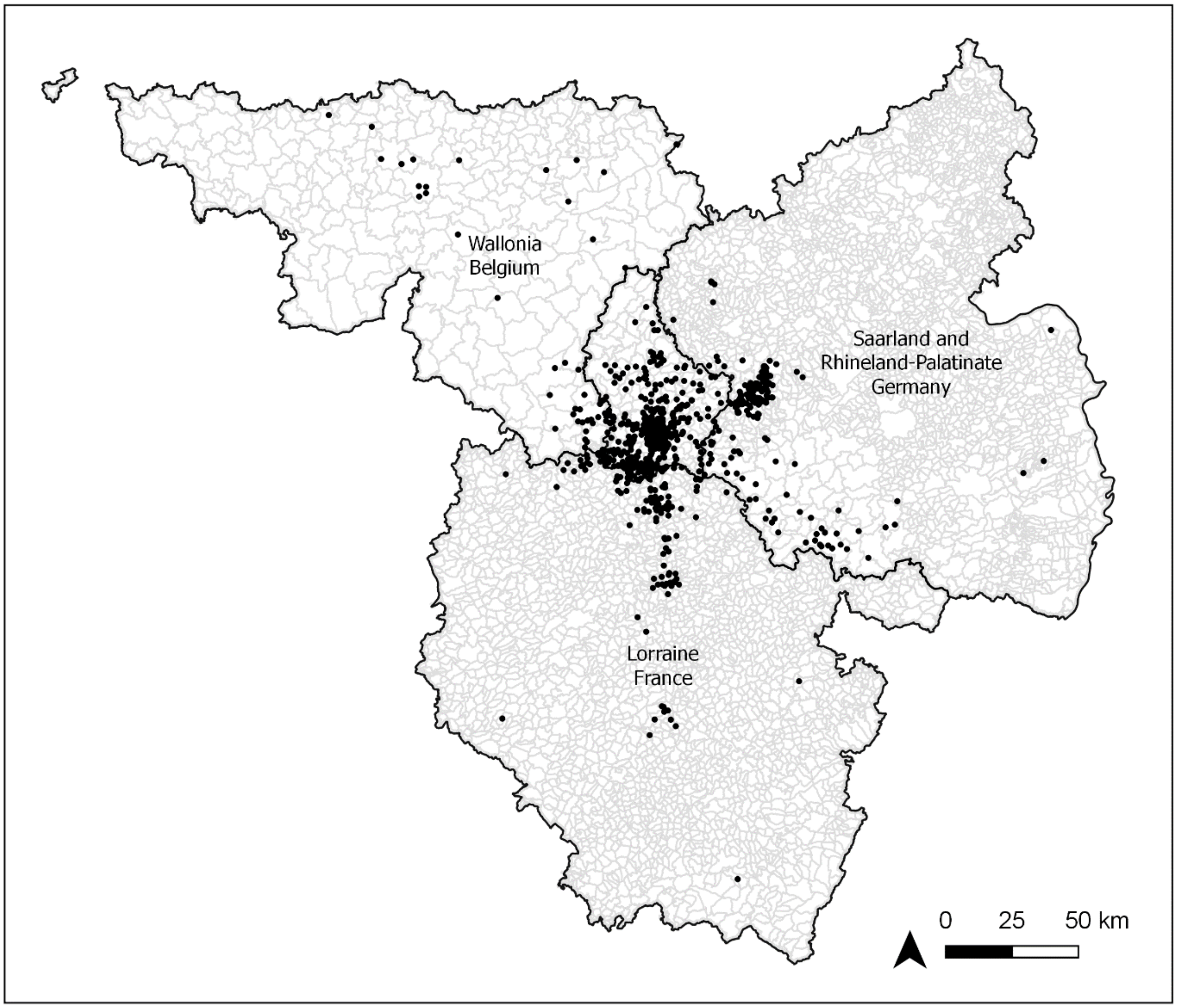


Figure 3 Communes of residence of the University staff living in the Greater Region (N=1044)

The move to Belval, which will impact most of the University staff members, offers a unique opportunity to modify the commuting mobility toward a more sustainable one. However, studies have shown (e.g. Vale (2013), Gardner (2009)) that a workplace relocation, even to a suburban transit-oriented center, may not, by itself, trigger modal shift toward low emitting transport modes. On the contrary, people would tend to stick or to switch to car use to minimize their commuting travel time in order to keep their travel time within acceptable limits (Bell (1991), Hanssen, (1995)).

Having the opportunity to study an important change in collective behavior, and, more importantly, to be able to identify opportune measures to face the unavoidable mobility issues that this political choice will bring is of paramount importance. The university has in plan to run a series of surveys, both for the staff and for the students. The first, which is described in this paper, was run in 2012, thus relatively early in time with respect to the actual relocation activities.

At the time of conduct of the survey in May 2012 the University counted 1095 staff members: 68% lived in Luxembourg, 17% in Germany, 11% in France and, finally, 4% lived in Belgium. Luxembourg-city hosted 33.9% of all staff. For these peoples, the relocation will bring significant changes in terms of commuting distance.

Five “non-Luxembourgish municipalities” (Trier (DE), Thionville (FR), Arlon (BE), Saarbrucken (DE), Metz (FR)) hosted 148 peoples (14.1% of the University staff population). As one can observe from Figure 3, residences are scattered over four countries. This will add an extra degree of complexity in the analysis as the respondents from the different areas will certainly experience completely different relocation effects.

## 3.3 State of the art

### 3.3.1 Workplace relocation

Vale (2013) highlighted that few scientific publications were available concerning major workplace relocation. The existing literature is mainly describing the impacts (in terms of modal split, travel distance and car ownership for instance) of workplace relocation from the city center to the suburb. This is, in a way, similar to what the University of Luxembourg will experience. Most studies (e.g. Aarhus (2000), Cervero and Wu (1998)) have observed an increase in car use for commuting even when the new location has a good access to public transport. Bell (1991) even described an increase in the number of employee owning a car. Cervero and Landis (1992) mentions that the most negatively affected employees were the city-center residents who experienced both a significant increase in travel time and travel distance. Surprisingly, Vale (2013) observed that 73.3% of the workers did not adopt a new mode. As already mentioned, this demonstrates strong transport mode inertia.

### 3.3.2 Travel Demand Management Measures

Private companies and major public institutions, as important trip attractors/generators, have an important role in the mobility debate. Since the end of the eighties, companies have developed initiatives called “mobility management” (Europe) ”travel plan” (UK) or Travel Demand Management (TDM) (USA) to reduce or control the number of single-occupant vehicles (SOVs) commuting (Van Malderen et al. (2012), Rye (2002)). Actions to reduce car (over-)use externalities take place at individual’s workplace (Vanoutrive et al. (2010)) mainly because of the repetitive and predictable patterns of the home-to-work trips (Van Malderen et al. (2009)).

Research suggests that implementation measures work best if they include a wise mix of carrot and stick (or pull and push) measures, and assuming that car users would be hostile to car use reduction is an judgment error (Goodwin (1995)). Users tend to accept push measures as long as they see them as fair (Rye and Ison (2005)). Fairness will however be a major issue in the context of our study, given the transnational characteristics of the trips and the different accessibility between residents and cross-border workers.

Independently from the company’s wish to decrease SOV (Single Occupancy Vehicle) commuting, several characteristics have a huge impact on the workers commuting trips. The density (both population and employment density), for instance, where companies are located has a great influence on the modal split used by the employee. The company characteristics in itself (structure size, sector of activity) have also clearly an impact on the commuting behavior of the employee working there (FPS Mobility and Transport (2010)).

Within an Employer-based mobility (EBM) program, companies can choose to implement a wide range of measures, e.g.:

*Decrease the need to travel*

Before wondering "How will I go there?" workers could wonder "Do I really need to go there?". Recent technological improvements have decreased the need to meet people face to face. Teleconference can advantageously replace a long trip followed by a short face to face meeting.

Teleworking is an efficient but often sensible way to reduce commuting trips. This permits to save time, to avoid stress of driving, etc. The compressed or flexible work week appear to be efficient measures in order to reduce the total number of journeys (and the related pollution) done by workers. This would mean for instance that people could accept to work 10h per day during 4 days (Van Malderen et al. (2009)). A flexible work time management also permits to workers to more easily combine professional and private life (FPS (2010)).

*Develop motorized SOVs alternatives*

Increasing car occupancy is the easiest way to decrease SOVs use. The cost saving potential of car-sharing is real and has been recently well described (Duncan (2010)). The use of existing platforms or the development of a new one can be imagined. To avoid fear of having no colleague for sharing the trip back home, a guaranteed trip back system can also be implemented.

A modal shift toward public transport can instead be reached through subsidizing. This obvious measure can be complemented by providing to all employees reliable information related to their personal home-to-work trips. This information can, nowadays, be given through several channels. Intranet, Corridor TV, Personalized-Travel Planners seem to be the most effective ways to inform efficiently the employee or even visitors of any institution (hospital, company headquarter, public administration...).

In some cases, the institution might develop a shuttle service. The shuttle can go directly at employee homes or specific stops (a train station, a central place...). In this study, one of developed scenarios is based on a higher subsidy of the PT subscription, the Mpass abonnement, which enables one to use the bus and train services at any time within Luxembourg.

*Increase soft modes use*

The optimization of pedestrian and urban cyclability is one the main useful tools to achieve sustainable urban mobility (Berloco et al. (2012)). In dense urban areas, cycling can be, on short distances, nearly as fast as car or public transport. Thus, the potential of biking should not be neglected for people working close to their home. Close to 25% of the Luxembourgish workers live within 5km of their workplace (Carpentier et al. (2009)). Moreover, De Hartog et al. (2010) have shown that the estimated health benefits of cycling were substantially larger than the risks of cycling relative to car driving.

Vandenbulcke et al. (2009) have listed potential barriers to bike use; fear of crime or vandalism, bad weather, hills, danger from traffic, social pressure and long commuting distances. Some measures implemented at the university level could mitigate the effects of these barriers. Increase the convenience to walk/bike as well as make it financially attractive seems to be the winning mix to reach non negligible soft modes modal shares. These are for example ordinary measures in cycling-friendly neighboring countries such as the Netherlands and Belgium.

Providing financial incentives under the form of a mileage cycle reward of €0.2 /km is a measure often implemented in Belgian workplaces, among public institutions especially.

In order to make the trip safe and convenient, well-known measures at the infrastructure and services level can be implemented. Washing and changing facilities, secured, covered and well located bike sheds, provide information on bike paths are example of usual cycling measures. Other, less used, actions can also be implemented, such as providing “company bikes” (electric or not), proposing interest free loans to buy a bike, proposing a guaranteed back trip in case of bad weather conditions (similar to the carpooling scheme).

The possible impact of the implementation of a mileage cycle reward of €0.2 /km will be tested later in the paper.

*Decrease car attractiveness*

According to Heran (2011) major modal shift towards public or active transport modes will not occur because of PT or Bike & Walk infrastructure improvements but by limiting car speed and freedom. Other solutions, less extreme, might lead to similar results in term of car use. A Parking Management scheme including a parking cost is described as one of the most effective to reduce single occupancy vehicle and thus lead to a modal shift towards other modes (Marsden (2006), Wilson and Shoup (1992)).

Numerous Parking Management schemes exist from the basic (fixed monthly cost) to the fairest and most imaginative one (wage related hourly fees, parking cash out strategies (Watters et al. (2006)). Rye and Ison (2005) described all the elements that need to be taken into account concerning a possible parking scheme implementation. The need for clear objectives, the charge and exemptions from charging, the process of introducing a charge, the scheme administration are examples of issues raised when institution are facing parking scheme implementation. Most problems and opposition can be overcome thanks a high level of consultancy, good and abundant communication campaign.

Since for private or public institutions implementing a charged parking scheme is probably the easiest and most efficient way to reduce car attractiveness, a fixed parking cost is one of the TDM measures that has been tested in this paper.

*Miscellaneous measures*

The designation of a mobility-coordinator is, in Belgium, one of the most implemented measures. The nomination of a mobility manager and the creation of a Mobility working group or steering group is also rather usual.

Providing a car fleet among important private or public institutions can lead to car commuting decrease. Indeed, according to Watters et al. (2006) the need of a car during workday is the first reason for choosing to drive to work.

| Mode | Measures |
|---|---|
| Cycling / Walking measures | Washing and changing facilities |
| | Develop a bike fleet system |
| | Subsidize bike sharing system registration |
| | Provision of rain clothes |
| | Interest free loans to buy a bike |
| | Agreement on discount with a local bike reseller |
| | Provide a Personalised-Cycling-Commuting map |
| | Bad weather condition lift |
| | Bike repair station |
| | Cycle mileage rate |
| General measures | Travel coordinator/Mobility Manager |
| | Information campaign |
| | Mobility working group creation |
| Public transport | Real time information (intranet, TV corridor…) |
| | Subsidized season ticket |
| | Develop a shuttle service |
| | Lobbying from local authority for service development or improvements. |
| Miscellaneous | (electric) car fleet for professional use |
| | Flexible working time |
| | Compressed week |
| | Teleworking |
| Car-sharing | Develop a new carpooling platform or promote existing initiatives |
| | Reserved car park for carpoolers |
| | Guarantee for the return journey |
| | Fleet car |

Table 2 Travel Demand Management measures

The previous section has shown that a wide range of TDM measures exists and can easily be implemented by private companies or public institutions. However, even if people can benefit from attractive measures, some people will stick to driving alone to work. Travel behavior is a field where emotions, habits and social pressure are active. A good example is the one given by Rye and Ison (2005), describing how employees were reacting to a charge parking scheme; “you’re charging us to go to work”.

Rye (2002) wondered if “travel plans: do they work?” and he managed to prove that, indeed, they work. Reductions in drive alone were ranging from 5% (implementation of basic and cheap measures) to 15% (implementation of several pull and push measures).

## 3.4 Data and methodology

Between half May 2012 and half June 2012, a staff travel survey was carried out. The aim of such survey is to discover how people at university travel and why. Up to that time nothing was known concerning the staff commuting behavior.

After appropriate cleaning and filtering, data concerning 329 individuals (out of 397) have been used. Some respondents did not accept to give us their postal code for privacy issues. Because home location was crucial information in this study, this led to important data suppressions.

The survey population, in terms of country of residence is rather close to the general University staff population, Indeed, 4,8% come from Belgium, 10% from France, 21, 2% from Germany and 63, 9% are

Luxembourgish residents. However, these figures are not similar to those concerning the entire job market in Luxembourg (11% from Germany, 11% from Belgium, 21,6% from France and 56,4% live in Luxembourg (STATEC, 2014).

### 3.4.1 Discrete choice theory

A simple Multinomial Logit model has been developed to model the impact of TDM measures implementation. Discrete choice models, following the original ideas of McFadden (1980) are widely used in transport modelling (see Ben-Akiva and Lerman, 1985). Three modes of transportation have been taken into account: car, public transport, and soft modes. In order to keep the model simple and the results easily understandable, three variables have been taken into account: travel time, travel cost and a dummy variable related to PhD status.

For the home-to-work trip, car travel cost has been set to 0.2€/km, public travel cost have been computed separately for each origin-destination pair while soft modes cost has been set to 0€.

Car and soft modes travel time have been gathered by a “Friendly Batch Routing” (Medard de Chardon et al., 2012) application that uses Google Maps API. Traffic density coefficients have been used to better represent the commuting time at peak hours. Public travel times have been collected on the national public transport platform “mobiliteit.lu”.

Finally, alternatives availability has also been defined. For instance, the use of car as a commuting mode is only possible if the respondent indicated to be in possession of a valid driving license and to have the possibility to use a car every day or if respondents stated to organize car-sharing with colleagues on a regular basis. The use of soft modes was assumed possible only if commuting trips did not exceed 16km (2h40 of walk). Public Transport (PT) use is assumed possible only for one-way trip shorter than 2h40min.

The software program BIOGEME (Bierlaire, 2003) has been used to run this model (Table 3). After testing a relatively large number of explanatory variables at our disposal, the following functional forms were found to be best fitting our dataset:

$$V_{n,CAR} = betatime \cdot [time\ car]_n + betaprice \cdot [price\ car]_n$$

$$V_{n,PT} = betaPT + betatime \cdot [time\ PT]_n + betaprice \cdot [price\ PT]_n + betaPhD \cdot [PhD]_n$$

$$V_{n,SOFT} = betaSOFT + betatime \cdot [time\ SOFT]_n + betaPhD \cdot [PhD]_n$$

| Name | Value | Robust Std err | Robust t-test | p-value | |
|---|---|---|---|---|---|
| ASC_CAR | 0.00 | | | | |
| ASC_PT | -0.648 | 0.283 | -2.29 | 0.02 | |
| ASC_SOFT | -0.678 | 0.416 | -1.63 | 0.10 | * |
| B_COST | -0.118 | 0.0467 | -2.53 | 0.01 | |
| B_PHD | 0.840 | 0.392 | 2.14 | 0.03 | |
| B_TIME | -0.0557 | 0.0115 | -4.86 | 0.00 | |

Table 3 BIOGEME output (* means insignificant result at 95% level of confidence)

Without any surprise, public transport and soft modes constant parameters were found negative (but soft mode constant parameter was found not significant) suggesting that, everything else being equal, the respondent would favor the car option.

The estimated coefficients for cost and time variables are negative, indicating that utility related to a transport mode will decrease if it becomes slower or more expensive. The Value of Time (VoT) reaches 28.32€/h (-0.0557 / - 0.118 * 60) which is close to reality.

By applying the model to the primary data set, 79% of the choices are modeled correctly. The adjusted Rho square value reaches 0.277 and the Final log-likelihood value -163.810 (Null log-likelihood =-233.568). Table 4 shows how the errors are distributed.

| | | Modelled Choice | | |
|---|---|---|---|---|
| | | Car | PT | SOFT |
| Revealed choice | Car | 158 | 9 | |
| | PT | 44 | 89 | 2 |
| | SOFT | 6 | 12 | 9 |

Table 4 Modelled choices versus revealed choices (n=329)

This calibrated model will be used to assess the impact of the various scenarios described in a next section. More complex models have been tested but provided unexpected results. Socio-economic variables have been included in the model presented in appendix A. All socio-economic constant parameters were found insignificant. Appendix B is another example of model with additional public transport variables (headway and number of necessary interchange during the commuting trip). Again, none of these two variables was significant.

Several hypotheses can partly explain these modeling difficulties. First, University staff population is very specific and discrete choice theory approach which is leading to data aggregation might not be the best methodology to exploit this data set. Secondly, other uncollected variables might have been helpful to refine our model. Indeed, variables such as comfort or attitudes toward car or public transport would have been precious. Notwithstanding these issues, the model used is methodologically valid and can be used with caution, like any other model, for forecasting.

## 3.5 Analysis

### 3.5.1 Commuting distance variation due to the workplace relocation

Because the travel survey respondents gave us information related to their postal address and their current working place (on which campus they work), it has been possible to compute the travel distance they will have to face after the university relocation to Belval.

As it can be seen in Table 5, because the university will move to a low-density area, only a few people (10.3%) will have a shorter travel distance. Around a third (30.3%) of the respondents will not be too much affected by the relocation but the majority (59.3%) of the staff members will have a longer travel distance. As expected, commuters from Luxembourg-city and Germany will have to face an important increase in their daily commuting distances.

| | | Before the relocation | | | | | |
|---|---|---|---|---|---|---|---|
| | | > 3 km | 3 to 10 km | 11 to 20 km | 21 to 50 km | < 50km | Total |
| After the relocation | > 3 km | | | | 6 | | 6 |
| | 3 to 10 km | | | 3 | 17 | | 21 |
| | 11 to 20 km | 6 | 41 | 12 | 5 | | 64 |
| | 21 to 50 km | 27 | 58 | 16 | 54 | 2 | 157 |
| | < 50km | | | | 47 | 34 | 81 |
| | Total | 33 | 99 | 31 | 130 | 36 | |

Table 5 Distance variation for university staff members after their workplace relocation

The Table below shows the commuting travel mode choice both for the entire working population in Luxembourg and for our travel survey respondents. The important difference between these 2 worker populations can be due to the education level difference, a higher environmental awareness, a different work flexibility, etc.

| | Car | | PT | | Soft modes | |
|---|---|---|---|---|---|---|
| | University figures | National statistics | University figures | National statistics | University figures | National statistics |
| Luxembourg | 49% | 74% | 38% | 15% | 13% | 11% |
| Belgium | 63% | 88% | 38% | 12% | 0% | 0% |
| Germany | 63% | 90% | 37% | 10% | 0% | 0% |
| France | 30% | 83% | 70% | 17% | 0% | 0% |

Table 6 Modal share comparison between cross-border workers and residents

### 3.5.2 The scenarios

First, the model parameters obtained previously will be used to assess the impact of the relocation alone. Travel time and travel costs have been modified to take into account the workplace relocation.

Second, a scenario is testing the effect of a parking fee implementation. This will be done by, simply, adding a fixed cost to the car transport cost.

In the third scenario the university would increase the PT subsidy and a monetary incentive is given to soft mode users (0.2€ /km).

### 3.5.3 Analysis of the results

Various scenarios have been developed to estimate the effect of the campus relocation and the impact of common Travel Demand Management measures. The estimated parameters of the model described previously have been re-used but travel costs and travel time have been adapted.

*Scenario 1: simple relocation*

This scenario is simply taking the workplace relocation into account. Travel cost and travel time have been adapted for all three transportation modes.

| | | FUTURE (Modelled Choice) | | |
|---|---|---|---|---|
| | | Car | PT | SOFT |
| BEFORE (Revealed Choice) | Car | 162 | 5 | |
| | PT | 75 | 59 | 1 |
| | SOFT | 13 | 14 | |

Table 7 Scenario 1: impacts of the workplace relocation

According to the model results, car use would increase of 25% while public transport mode and soft mode use would decrease of, respectively, 17% and 8%. After having presented the Table 5, the results presented in Table 7 are not surprising. Indeed, the new campus is moving to a low density area (and thus with few staff members living in the vicinity) leading to longer commuting distances for the vast majority of the people while only few people will benefit of shorter commuting distances. Residents of Luxembourg-City (and surrounding municipalities) and residents of Germany will particularly suffer from this situation.

Only one respondent would quit using public transport and use soft modes instead. Until now few people are living in that area, this is drastically limiting soft modes use in our model.

*Scenario 2: fixed parking cost*

This scenario assumes a monthly parking cost of 110€ or a fixed daily parking cost of 5€. The situation with a daily parking fee is compared to the situation after the relocation (scenario 1 versus scenario 2). As it can be observed on the below Table 8, the implementation of a parking would imply a modal shift for only 11 peoples (3.3%).

| | | Scenario 2, fixed parking cost | | |
|---|---|---|---|---|
| | | Car | PT | SOFT |
| Scenario 1, simple relocation | Car | 239 | 10 | 1 |
| | PT | | 78 | |
| | SOFT | | | 1 |

Table 8 Scenario 2: impacts of the fixed parking cost (own production)

This modal shift towards PT is surprisingly low compared to the rather high parking fee. However, for people commuting long distances by car a 5€/day parking fee would represent a low additional cost.

*Scenario 3, Soft modes incentives + PT increased subsidy*

In this scenario, the implementation of a soft mode incentive in addition to an increase in the subsidy of the Mpass, the national public transport annual pass, is considered. Currently the Mpass is already partly subsidized but the share paid by the University might increase. In this last scenario, the PT cost is set to 0€ (100% subsidy) while the soft mode incentive would be a mileage cycle/walk reward of €0.2 /km.

As it can be seen from the below Table 9, soft modes incentive would have no effect at all on commuting mode choice. This can partly be explained by 1) the equipment level, indeed not everybody has a bike or the possibility to use one 2) the important travel time would strongly impact soft mode utility.

| | | Scenario 3, Soft and public modes incentives | | |
|---|---|---|---|---|
| | | Car | PT | SOFT |
| Scenario 1, simple relocation | Car | 249 | 1 | |
| | PT | | 78 | |
| | SOFT | | | 1 |

Table 9 Scenario 3: impacts of the soft modes incentives and PT increased subsidy

## 3.6 Conclusion

Two different hypotheses have been developed and tested in parallel in this article. First, it has been assumed that TDM measures have an important role to play (Vanoutrive et al. (2010)). However, it has also been assumed that after major workplace relocation in a peripheral area, workers tend to use car and that travel mode choice inertia might be a strong deterrent toward sustainable travel mode choice shift.

Can TDM measures in a peripheral workplace location be effective? According to this study and the methodology used, investments in favor of public transport and active modes could turn out to be expensive and not efficient. Soft modes incentives may be particularly effective in dense areas. However, suburban areas are less easily accessible, safe and convenient to reach by soft modes. Thus, this kind of measures which can be difficult to implement can have a high cost/benefit ratio. The same also holds for public transport incentives; while major cities are easily and directly accessible by public transport, peripheral areas can only be accessible using a chain of modes integrating public modes. This complexity and the extra time often needed for interchanges is a strong deterrent. As seen in the results, strong PT subsidies will not affect workers travel choice if the PT travel time is not competitive compared to car travel time.

Measures that negatively affect car travel time and car travel cost may be the only way to reduce car commuting in any effective manner. After nearly a century of car infrastructure development, reducing car accessibility and freedom does not seem anymore as an inconceivable proposal (Heran (2011)).

Other TDM measures that have not been considered in these scenarios could be developed. Because in most cases, car travel time is shorter than PT commuting times, car-sharing might seem an appealing solution in order to increase car occupancy vehicle. Teleworking and flexible work time are also important tools when it comes to improve staff member´s professional/private life balance.

In future steps of this analysis, more refined models may be used to confirm the results developed in this article and perhaps to gain insight into the rather special conditions at which university commuters in Luxembourg must make their daily travel choices. For example, additional variables and multimodality may be taken into account. Daily activity (related to professional life or not) could be taken into account as well. These will help us at possibly justifying data calibration issues and partly identify other relevant factors for commuters' mode choices, and in turn test more innovative and personalized travel demand management solutions.

## Appendix A. Multinomial Logit models with socio-eco characteristics

As already mentioned, difficulties were met in trying to develop more complex models. The model presented below includes different socio-economic variables.

$$V_{n,CAR} = betatime \cdot [time\ car]_n + betaprice \cdot [price\ car]_n$$

$$V_{n,PT} = betaPT + betatime \cdot [time\ PT]_n + betaprice \cdot [price\ PT]_n + betaPhD \cdot [PhD]_n + betaADMIN \cdot [ADMIN]_n + betaGENDER \cdot [GENDER]_n + betaKIDS \cdot [KIDS]_n + betaPROF \cdot [PROF]_n + betaSTATUS \cdot [STATUS]_n$$

$$V_{n,SOFT} = betaSOFT + betatime \cdot [time\ SOFT]_n + betaPhD \cdot [PhD]_n + betaADMIN \cdot [ADMIN]_n + betaGENDER \cdot [GENDER]_n + betaKIDS \cdot [KIDS]_n + betaPROF \cdot [PROF]_n + betaSTATUS \cdot [STATUS]_n$$

Where ADMIN is a dummy variable indicating if the staff member holds an administrative position. The reasoning is the same for PhD and PROF variables. GENDER variable is equal to one for males. KIDS dummy variable indicates if yes or no staff members have dependent kids at home. Finally, the STATUS dummy variable is equal to one for staff members living in couple.

| Name | Value | Robust Std err | Robust t-test | p-value | |
|---|---|---|---|---|---|
| ASC_CAR | 0 | | | | |
| ASC_PT | -0.171 | 1.82E+07 | 0 | 1 | * |
| ASC_SOFT | -0.203 | 1.82E+07 | 0 | 1 | * |
| B_ADMIN | -0.568 | 1.82E+07 | 0 | 1 | * |
| B_COST | -0.12 | 0.0489 | -2.46 | 0.01 | |
| B_GENDER | -0.0722 | 0.348 | -0.21 | 0.84 | * |
| B_KIDS | 0.0784 | 0.365 | 0.21 | 0.83 | * |
| B_PHD | 0.442 | 1.82E+07 | 0 | 1 | * |
| B_PROF | -0.249 | 1.82E+07 | 0 | 1 | * |
| B_STATUS | -0.0899 | 0.413 | -0.22 | 0.83 | * |
| B_TIME | -0.0558 | 0.0115 | -4.86 | 0 | |

Table 10 BIOGEME output (* means insignificant result at 95% level of confidence)

In addition to low variable significance, the adjusted rho square is decreasing (0.257) as well as the Final log-likelihood (-163.550).

## Appendix B. Multinomial Logit models with additional public transport variables

In the below model, two additional variables have been introduced. CHANGE variable indicate how many changes are necessary on the commuting trip using PT. Headway (in minutes) is equal to the inverse of the frequency per hour.

$$V_{n,CAR} = betatime \cdot [time\ car]_n + betaprice \cdot [price\ car]_n$$

$$V_{n,PT} = betaPT + betatime \cdot [time\ PT]_n + betaprice \cdot [price\ PT]_n + betaCHANGE \cdot [CHANGE]_n + betaHEAD \cdot [HEAD]_n$$

$$V_{n,SOFT} = betaSOFT + betatime \cdot [time\ ]_n + betaPhD \cdot [PhD]_n$$

| Name | Value | Robust Std err | Robust t-test | p-value | |
|---|---|---|---|---|---|
| ASC_PT | 0 | 0.29 | -2.18 | 0.03 | |
| ASC_SOFT | -0.631 | 0.415 | -1.02 | 0.31 | * |
| B_CHANGE | -0.425 | 0.279 | 1.13 | 0.26 | * |
| B_COST | 0.316 | 0.0486 | -1.82 | 0.07 | * |
| B_HEAD | -0.0882 | 0.0125 | 0.72 | 0.47 | * |
| B_TIME | 0.00899 | 0.0126 | -4.87 | 0 | |

Table 11 BIOGEME output (* means insignificant result at 95% level of confidence)

## Appendix C.

This chapter relied on 2012 cross sectional travel survey data and the scenarios were developed based on available information at that time. Because additional travel surveys have been implemented in 2014 and 2016, a comparison between forecasting made in 2014 and more recent data is possible.

The data from the 2016 (collected between the 16th June and the 1st of July) University staff travel survey reveals from the 593 valid replies collected (37% response rate) 358 were employees working on Belval campus. At this period, data provided by the human resources department reveal that 1683 employees (included PhD students) were working at the university and 967 were working on the new Belval site. Thus, the travel survey data also represent 37% of the entire university staff population in the new campus.

The modal split among the Belval workers is 51% by car, 46% by public transport and 3% by soft modes (walking, cycling). These statistics are slightly different than the modal split for the entire respondents (44% by car, 51% by PT, 5% by soft modes). Interestingly, the modal split among the Belval workers seems linked to their previous working place. Indeed, below, picture 4 shows that the modal split is not the same for the people that have started to work at the University in Belval (the "Joiners") or the staff members that had to face a workplace relocation either from Kirchberg, Limpertsberg or Walferdange (the "Movers"). Car use among the "Movers" is 13% more important than for the "Joiners". The difference in term of commuting distance between Movers (average = 40.3km, median = 30.2km) and joiners (average = 32.6 km, median = 22.8km) partly explain this difference.

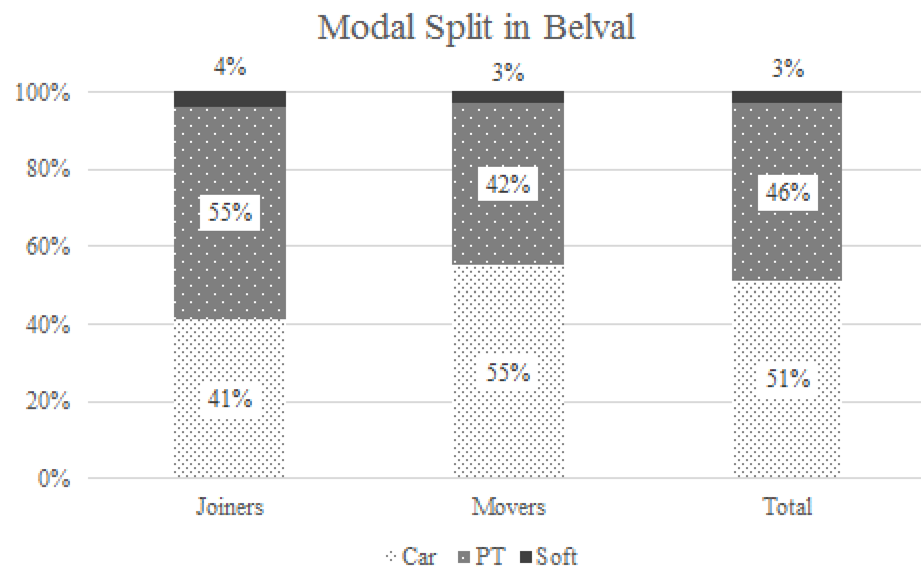


Figure 4 Modal split in Belval

After comparing the modal split obtained via the 2016 staff travel survey, it turns out that none of the scenarios developed has produced similar statistics. Scenario 1 which was forecasting the effect of a simple relocation gave as a result a 25% modal shift toward car. Of course, in light of this forecasting error, elements which had an effect are worth being discussed.

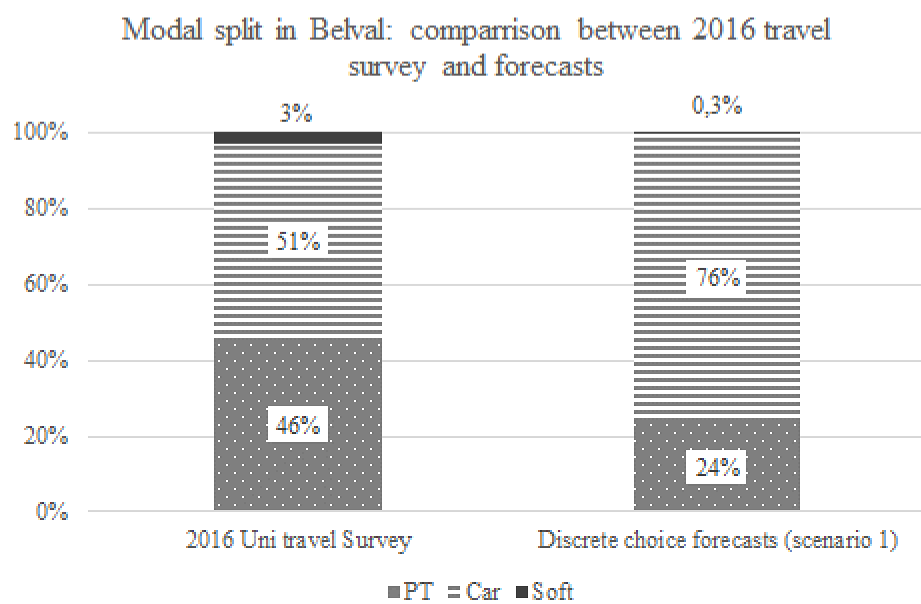


Figure 5 Modal Split in Beval: comparison between 2016 travel survey and forecasts

First, by looking at the aggregate modal split for UL staff members in Belval for 2012 (car= 51%, PT= 40%, soft = 9%) and 2016 (car = 51%, PT=46%, soft =3%) it is possible that mode choice inertia as described by Vale (2013) had led all individuals to stick to the mode they were using. However, a first element to observe is that the Movers, in other words, the population on which has been done the forecasting analysis have higher car use level. By observing the commuting mode choice only for the Movers, the gap between the 2012 forecasts and the 2016 travel survey data is decreasing a bit.

Second, to model the modal choice before the relocation congestion coefficient have been used on free flow speed time (provided by google map API) this has not been done for the situation at Belval. Not using congestion coefficient for the new workplace probably led to an artificially high car attractiveness.

Third, the parking issue in Belval might have influenced staff toward car use. The university is providing parking for 60€ a month while other parking propose monthly pass for 45€. The 2016 also reveals that some staff members were requesting the MPASS, a highly subsidized transit pass valid in the entire country, in order to access to a park & ride facility located in Beval. Of course, public subsidy (both from the University and the national government) for public transport use should not be used only by car user who want to park for a cheap price.

In addition to be the campus with the highest car use for the commuting trip among the university travel survey respondents, it's also the campus that exhibits the lowest satisfaction level for the commuting trip. Since the 2012 travel survey, a single question concerning the overall commuting trip satisfaction was asked to the respondents. The information regarding the commuting trip is seen as an indicator of possible long-term changes. Indeed, after being "very unsatisfied" of your commuting trip for a long period, the probabilities that workers would adopt coping strategies is increasing. Among these adaptation strategies, workers can, for instance, switch to a faster mode, change the relocation or even quit their current job position.

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# 4

# On the consistency between commuting satisfaction and traveling utility

Because low commuting satisfaction among workforce might potentially lead to negative impacts (e.g. in term of modal split or a loss of some employees) analyse what are the determinants of commuting satisfaction is crucial. Consequently, the next chapter is dealing in detail with commuting satisfaction and how it is related to the utility concept (the logsum function of utility to be precise) that has been used in the previous section.

According to random utility theory, there is no clear distinction between the utility inferred from observed choices (decision utility), the experienced outcome of decision makers' (experienced utility) or their retrospective evaluation (remembered utility). While empirical experiments have shown that decision utility and remembered utility do not perfectly coincide, little is known regarding the magnitude of this discrepancy, especially in the transport field. Using a cross-sectional travel survey, the objective of this paper is to quantify the relationship between commuters' stated choice satisfaction (a proxy for remembered utility) and the Logsum function of the utility of all available modes of transport (decision utility). This is of tremendous importance, as implemented transport policy measures, which aim to increase the overall decision makers' utility, may have low impact on their satisfaction level and thus be ineffective. Results indicate that the utility Logsum is associated with respondents' commuting satisfaction. However, context specificities have an important impact on this association.

This chapter is based on the paper: Sprumont F., Astegiano P., Viti F. (2017). On the consistency between commuting satisfaction and traveling utility: the case of the University of Luxembourg. *European Journal of Transport & Infrastructure Research* . 2017, 17(2), 248-262.

## 4.1 Introduction

For many decades, Discrete Choice Theory (DCT) (McFadden, 1980) has been successfully applied to travel mode choice modelling (Ben-Akiva & Lerman, 1985). Random Utility Models (RUM), which are currently among the most popular DCT methodologies used in travel mode choice behaviour, are indeed well suited for mode choice understanding and forecasting. Their main advantage is their relative simplicity in relating choice decisions, which can be observed and/or stated through opportunely designed surveys based upon what-if scenarios, to quantifiable variables, such as travel times, delays, public transport fares, etc.

In economy, utility is defined as a measure of preference for a decision maker over a choice set (Varian, 1992). The most popular way to adopt this concept in travel behaviour analysis is to use it within an optimization problem where travellers choose their travelling options such that their overall utility is maximised. In this framework, utility is defined as a combination of different attributes related to a specific decision, e.g. whether using a certain mode of transport for reaching a location where to do an activity. In this decision-making process framework, the definition of utility is of crucial importance. Ben-Akiva and Lerman (1985) defined it as an index of attractiveness, which has a direct relation with attributes related to a specific travelling purpose, the available travelling options and attributes related to the decision maker (e.g. socio-economic characteristics).

Kahneman et al. (1997) highlighted the necessity to distinguish various types of utility and were the first to differentiate concepts such as decision or experienced utility. The concept of utility commonly used in mode choice modelling is referred to as decision utility, while the experienced outcome of a mode choice, instead, is called experienced utility (Ettema et al., 2010). Remembered utility is simply the retrospective evaluation of past decisions. Utility inferred from observed choices (decision utility) is not the same as the experienced or the remembered utility (Kahneman & Sugden, 2005). The discrepancy between ex-ante (decision utility) and ex-post (experienced or remembered utility) utility concepts has been demonstrated using empirical experiments (Kahneman et al., 1997) and is now widely adopted (Ettema et al., 2010; Abou-Zeid, 2009; Abou-Zeid & Ben-Akiva, 2012; Chorus & de Jong, 2011; De Vos et al., 2016). Ettema et al. (2010) and Abou-Zeid (2009) were the first to raise this question in travel behaviour research.

It is well known that travel is a derived demand, not a proper activity that individuals wish to undertake for their own sake (Banister, 2008). The activity at the destination is valuable, not the trip. However, characterizing the way in which traveling is a derived activity is a debated issue (see Mokhtarian & Salomon (2001) and Redmond & Mokhtarian (2001)). According to various authors (St-Louis et al., 2014; Whalen et al., 2013) positive utility and satisfaction feelings have been observed for traveling. Furthermore, this was observed for commuting trips as well as for leisure trips (i.e. where the trip is the activity) or trip to leisure activities. Redmond & Mokhtarian (2001) showed that commuting trips are not unequivocally a source of disutility to be minimized.

To some extent, this is in line with the seminal work of Kahneman et al. (1997) which showed, using empirical experiments, that in addition to being distinct from decision utility, experienced utility is not always directly maximized by decision makers. The peak-end rule for instance (see Kahneman & Thaler (2006) for a recent discussion) postulates that when evaluating an event, individuals are greatly influenced by the event's most intense period and by its ending intensity.

While some authors such as Chorus & de Jong (2011) or Abou-Zeid & Ben-Akiva (2012) discussed the possible solutions to close the gap between experienced and decision utility, few publications have tried to quantify the relation between both concepts. Accordingly, the main objective of this paper is to better understand the relation between commuting utility, quantified by a multinomial logit model, and stated satisfaction. Using economic terms, our objective can be summarized as: analysing the link between decisions utility and remembered utility evaluated for repeated commuting travels. The hypothesis used in this work is that stated travel satisfaction and decision utility are strongly positively correlated. If this holds true, then interventions aiming at achieving system goals while not reducing the overall satisfaction of the users are likely to be effective. Our study contributes to verify this hypothesis and to identify reasons for which decision utility may in some conditions be a good substitute of commuting satisfaction, and in which cases other utility components may be as important, if not more important, as those used in the travelling utility concept.

This work is in line with a previous study of Chorus (2012), where satisfaction and decision utility where also systematically compared, but the analysis is here done at both aggregated and disaggregated levels, using classical cross-sectional travel surveying and the results obtained are also relatively different.

## 4.2 Satisfaction determinants overview

Having an intrinsic link with emotions, travelling satisfaction is a difficult concept to quantify, or to characterize with a functional relationship. Mokhtarian & Salomon (2001) indicated that the utility for travelling has 3 main components: the utility for any activity that can be done during the trip, the utility of the activity at destination and, finally, the enjoyment of travelling. The utility regarding the activity at destination is often taken into account and controlled. Intuitively, leisure activities generate more satisfaction than commuting trips. Ory & Mokhtarian (2005) give an interesting example: “Thus, two individuals traveling to the same flight may experience the travel differently due to their difference in trip purpose”. Regarding the activity that can be conducted while travelling, a large range of activities can be experienced. Read a book, listen to news, talk show, podcast, music, audiobook, discuss with people, have phone call, work, think, relax are example of ways to make best use of the available travelling time (for an exhaustive list, readers might consult Páez & Whalen (2010) and St-Louis et al. (2014)). The enjoyment of the trip in itself is the third and last dimension. Scenic beauty, nice landscape, speed excitement are examples of feelings than can improve a trip’s utility.

St-Louis et al. (2014) interestingly distinguished the determinants for travel satisfaction into 2 classes: external factors and mode-specific attributes and, on the other hand, internal and non-mode specific factors. The first category refers to “objective elements” of a commute such as travel time, travel cost, travel mode, road congestion state. Intuitively, Turcotte (2011) found that satisfaction decreases with travelling time and that the congestion level was an important source of dissatisfaction for the travellers. Each travelling mode has its own characteristics that can influence trip satisfaction. Soft modes (walking and biking) are usually the ones associated with the highest satisfaction levels. The least satisfied travellers are most frequently the ones using the public transport system. Thus, car users have an intermediate satisfaction between soft modes users and public transport users (Páez & Whalen, 2010). As expected, the results of St-Louis et al. (2014) showed how weather conditions have a stronger impact on soft mode users than on public transport users. Drivers are the least impacted commuters by weather conditions such as snow or rain. Interestingly, the authors also mentioned some bias in the satisfaction rating. Indeed, mode-captive people might not rate objectively their travelling mode. Internal and non-mode specific factors refer to commuter personality, behaviour and preference. Of course, socio-demographic characteristics play an important role in the way individuals take decision and experience activities. But other factors such as travellers’ values, attitude towards the mode and lifestyle play an important role in travelling experience as well (Ory & Mokhtarian, 2005). Two travellers living in the same building, commuting to the same place with the same travelling mode might evaluate their trips differently.

Very few studies relate satisfaction with attributes linked to the planned activities and the available modes of transport. Abou-Zeid (2009) proposed a commuting satisfaction model that links activity and travel choices using a well-being maximising formulation. She also identified the main factors for both work and non-work trips that influence well-being using a structural equation modelling approach. Ettema et al. (2011; 2013) developed and tested, using an SP survey approach involving hypothetical trips, a measure of satisfaction based on the concept of Subjective Well-Being, which has been introduced as alternative to the more traditional utility concept. However, the Subjective Well-Being concept depends on the choices' outcome and not only on the expected value of the systematic components. A recent study was performed by Chorus (2012), where hypothetical scenarios were designed and presented to a group of respondents to test the correlation between the Logsum (for both utility-maximising and regret-minimising functions) and stated satisfaction measures.

## 4.3 Methodology

This paper aims to understand the relation between the utility of commuting with a particular mode of transport, which is inferred from observed choice (decision utility) and stated satisfaction (a proxy for remembered utility). In order to reach this goal, the utility-based Logsum as adopted in Chorus (2012) is computed and then it is compared to stated satisfaction using two well-established approaches, namely multiple regression analysis and one-way Analysis of Variance (ANOVA). The contribution of this paper lies in the validation of this approach on another dataset in which mode choice decisions instead of route choice decisions are used. Furthermore, the findings in our study provide a significantly higher correlation between utility and satisfaction with respect to the findings reported in the existing literature.

Random Utility Theory (Ben-Akiva & Lerman, 1985) is based on the hypothesis that every individual is a rational decision-maker, which aims at maximizing the utility related to his choice. In particular, the generic decision-maker i, when making a choice, considers mutually exclusive alternatives that constitute his choice set; he then assigns to each alternative j in his consideration set a perceived utility and selects the alternative that maximizes this utility; the utility associated to each choice alternative depends on a number of attributes of the alternative itself and/or of the decision-maker. The utility function can be expressed as the sum of two terms: a systematic utility and a stochastic residual . The systematic part represents the mean utility perceived by all decision-makers having the same choice context while the residuals capture the unknown deviation of the utility perceived by user i from this mean value and capture the combined effects of the various factors that introduce uncertainty in choice modelling. The deterministic utility is instead usually assumed as a linear-additive function of weights of the attributes . Therefore:

$$U_j^i = V_j^i + \varepsilon_j^i \qquad (1)$$

Where

$$V_j^i = \sum_k \beta_k \; X_{kj}^i \qquad (2)$$

Among the different random utility models, the simplest and most popular is perhaps the Multinomial Logit. It is based on the assumption that the random residuals are independently and identically distributed as Gumbel random variables with zero mean and variance equal to $\frac{\pi^2}{6}$ . Consequently to this assumption, the probability of choosing alternative j from among those available (1,2,…,m) can be expressed as:

$$p[j] = \frac{\exp(V_j)}{\sum_{i=1}^{m} \exp(V_i)} \tag{3}$$

The logarithm of the denominator of equation (3) provides the aggregated utility that the traveller receives from the different alternatives and is commonly referred to as the Logsum:

$$LS_{RUM} = E\left[max_{j=1,\ldots J}\left\{U_j\right\}\right] = \int_{\varepsilon}\left[max_{j=1,\ldots J}\left\{U_j\right\} \cdot f(\varepsilon)\right]d\varepsilon = \ln[\sum_{j=1,\ldots J} \exp\left(V_j\right)]$$

The Logsum gives the opportunity to have a single scalar measure representing multiple alternatives at once. Mathematically, it allows having an aggregated measure of all potential options that a traveller may have in its evaluation set. Chorus & de Jong (2011) define the Logsum as “the expected maximum utility associated with a traveller’s choice set”. For this reason, it has been regarded in the literature as a suitable metric providing a value to user benefit, and it is commonly used as a measure of accessibility (Geurs, 2006).

A notable property of the Logsum is that it monotonically increases in value if a new alternative is added, even if its utility is very low. On the other hand, only alternatives with a sufficiently comparable utility with respect to the best alternative increase the value significantly. This property is associated to the intuitive sense of appreciation for having a larger set of alternatives where to choose the travelling mode. Hence, in mode choice, this expression is commonly adopted to compare two choice sets made of different travelling alternatives.

## 4.4 Case Study

### 4.4.1 Luxembourg, the heart of a cross-border region

At the heart of Europe, encompassing a total area of 2586 km², the Grand-Duchy of Luxembourg is a small country facing big mobility challenges. Every day, in addition to the commuting trips of its 563 000 residents, the country welcomes 170 000 cross-border workers, representing 43% of the total working force (STATEC, 2016). These cross-border workers coming from Belgium, France and Germany generate an important pressure on the transport infrastructure of the country. While 76% of the workers living in Luxembourg commute by car, the share is reaching 89% for cross-border workers (Carpentier & Gerber, 2009). Inside Luxembourg, the public transport use is relatively low compared to the high service quality both in terms of frequency and coverage (Klein, 2010). As mentioned by Epstein (2010), high car use may be explained partly by the dense motorway network and the positive image associated with car ownership. As far as commuting mode choice is concerned, the important difference between resident and cross-borders workers is mainly related to home-to-work distances. For the residents, the median commuting distance reaches 12km while it reaches 40km for the cross borders commuters (Carpentier & Gerber, 2009). Of course, such long distances are incompatible with soft modes use and hardly compatible with public transport use. This difference in trips characteristics and mode availability between cross-border workers and residents are, as previously argued, commuting satisfaction determinants (Turcotte, 2011; St-Louis et al., 2014).

### 4.4.2 The University of Luxembourg

Founded in 2003, the University of Luxembourg (the only University in the country) is welcoming every-day 6500 students and 1500 staff members. The majority of the University activities are located on three different campuses which are in Luxembourg-City (namely Kirchberg and Limpertsberg campuses) or a few kilometres away from the city centre (Walferdange campus). Since its creation, the university has constantly grown in total population and has now reached a limitation due to the infrastructure size. To solve this issue and to foster land-use polycentric development the national government has imposed the relocation of the University in Belval, a new town located around twenty kilometres southwest of the capital.

This workplace relocation will greatly impact the commuting behaviour of the staff members, which are, in line with the national trends, scattered in and outside of the country, with a significant number of cross-border workers. In our previous study (Sprumont et al., 2014) involving an earlier travel survey data analogous to the one described in this paper, we showed that the most impacted staff members will be the German workers while only a few people will decrease their commuting distances. In general, this workplace relocation will increase the commuting of the University staff members of, on average, 18% (from 28.7 to 33.8km).

Currently, the university is developing measures to increase staff members' satisfaction regarding their home-to-work trip in order to compensate for the loss caused by the government targets and in general by the relocation. A carpooling platform, a shuttle service between campuses and a car-sharing system are running from mid-September 2015. These services have been introduced with the objective of compensating the general loss of accessibility. Hence, assuming that the positive correlation between commuting satisfaction and the utility satisfaction measure expressed by the Logsum is verified in this study, we may then use the predictive properties of the latter model to evaluate the impact of these services.

### 4.4.3 The 2014 / 2015 travel survey

Between December 23rd and January 23rd, around 500 respondents replied to the 2014/2015 staff's travel survey. This means that 34% of the staff members (including PhD students) replied to the survey. Appendix B provides an overview of the resulting key figures. Such surveys are a great tool to monitor the commuting behaviour and to assess the implementation of Travel Demand Management (TDM) measures. The survey collected standard information regarding socio-demographic status, transport mode availabilities, and selected commuting mode.

The question regarding the (stated) commuting satisfaction was formulated as follow:

"Are you globally satisfied by your daily work commute? (If you take into account elements such as the cost, the distance and the stress caused by your home-to-work trips)".

The respondents had the choice between very unsatisfied, unsatisfied, satisfied and very satisfied (coded as Sat1, Sat2, Sat3, Sat4 in the appendix C). This four-point Likert scale question without neutral answer forced the respondent to attribute a positive or negative rate to their commuting trips. As usual when using Likert scales, the extreme response might be underused, showing a desire to not be perceived as a person with extreme feelings.

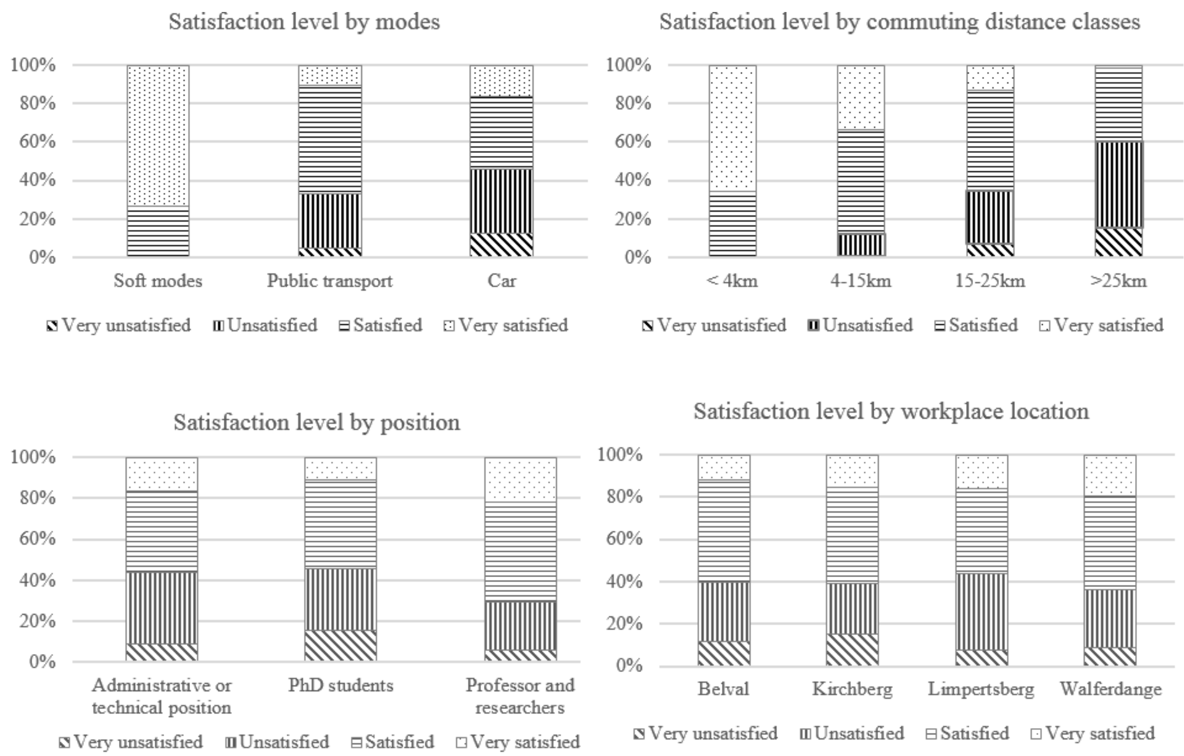


Figure 6 Satisfaction levels

Figure 6 presents satisfaction level's variation according to 4 variables, namely selected modes, commuting distance classes, work position and workplace location. Our data, similarly to the reported scientific literature, shows higher levels of satisfaction for soft mode use. Indeed, 100% of the walkers or cyclists are satisfied or very satisfied. The travel survey respondent exhibits higher satisfaction level for public transport use opposed to car use which is different from what has been observed by Turcotte (2011). Commuting satisfaction levels also seem to be negatively correlated with home-to-work distance. While soft modes and public transport use normally generate higher satisfaction levels, high travelling distances are naturally not compatible with soft mode and hardly compatible with public transport use, except for the routes served by a railway connection. The work position, a good proxy of the income level, also affects the commuting satisfaction. PhD students are the least satisfied of their commuting trip. Further research is needed but using university travel survey information, income level seems to be positively correlated with higher satisfaction levels. Because the various campuses all present different car and public transport accessibilities, different satisfaction levels would have been expected but no big difference is observed.

Important behavioural mode choice determinants such as attitude, subjective norms and perceived behavioural control which, according to Ajzen (1985), influence intention and finally decision's choice were not collected in this survey. Thus, the inclusion of these variables, which have been described as important satisfaction determinants by Ory & Mokhtarian (2005) in the MNL model, is unfeasible for this study.

## 4.5 Results

The aim of this paper is to verify whether Random Utility Maximizing Logsum and the stated satisfaction for the commuting mode of transport are positively correlated. In particular, we aim to express the Logsum as a single measure taking into account all mode alternatives available to the respondent.

In order to compute the utilities for each alternative, a Multinomial Logit Model was formulated and calibrated. The systematic part of the utility function for the three modes of transport that have been considered (CAR, PT, SOFT), takes the following form:

$$V_j^i = ASC_j + B\_TIME_j * Ttime_j + B\_COST_j * Cost_j + B\_PHD_j * PHD^i + B\_PROF_j * PROF^i \quad (5)$$

Where i and j are respectively the user and the mode alternative. Ttime and Cost are the travel time and travel cost associated with each alternative. PHD and PROF are two dummy variables that take value 1 if the user is a PhD student or a Professor (or postdoc researcher level) at the University of Luxemburg and zero otherwise. ASC is the so-called Alternative Specific Constant, which appears on all alternatives except one, and represents somewhat a systematic preference for certain modes, which is not captured by the systematic component.

Car cost has been set up to €0.15/km, no travelling cost has been assigned to soft mode use and public transport cost has been computed by dividing the yearly transport pass cost by an approximation of the total annual number of home-to-work trips (420). Estimating public transport travelling cost for each individual is far from easy.

First, based on the postal code, it has been assumed that individuals were commuting from the closest bus stop / train station which might represent an oversimplification in some instances. Second, some train stations recently introduced parking fees, and the collected data is insufficient to correctly identify their costs. Concerning the travelling time, a "Friendly Batch Routing" (Medard de Chardon & Caruso, 2012) application running in combination with the Google Maps API was used to obtain car travelling time and origin-destination distance. No congestion coefficient has been used in this study. Soft modes have been assumed to be characterized with a speed of 11km/h, an intermediate speed between walking and cycling.

In Table 12 the results of the MNL calibration are shown. The model was calibrated with the support of the software package BIOGEME (Bierlaire, 2003). The sign of the resulting parameters are all found consistent. The value of the ρ2 is 0.3 and the efficiency of the model reaches 77%. The value of the ASC_PT and B_PHD should be analysed with caution due to their relatively high p-value.

| Name | Value | Std err | t-test | p-value |
|---|---|---|---|---|
| ASC_CAR | 0.00 Fixed | | | |
| ASC_PT | -0.229 | 0.327 | -0.70 | 0.48 |
| ASC_SOFT | -0.936 | 0.397 | -2.36 | 0.02 |
| B_COST | -0.132 | 0.026 | -2.51 | 0.01 |
| B_PHD | 0.379 | 0.400 | 0.95 | 0.34 |
| B_PROF | 0.384 | 0.283 | 1.35 | 0.18 |
| B_TIME | -0.0513 | 0.0101 | -5.10 | 0.00 |

Table 12 Results of the MNL calibration

### 4.5.1 Multiple regression approach and ANOVA analysis

Given the results of the calibration process (see Table 12), it was possible to compute the utility-based Logsum expressed in eq. (4). Below, Figure 7 provides a first overview of the relation between the utility of the selected mode and the satisfaction level. From a visual inspection, it seems that our primary hypothesis can be confirmed. There appears indeed to be a positive relation between the utility of the selected mode and the satisfaction levels.

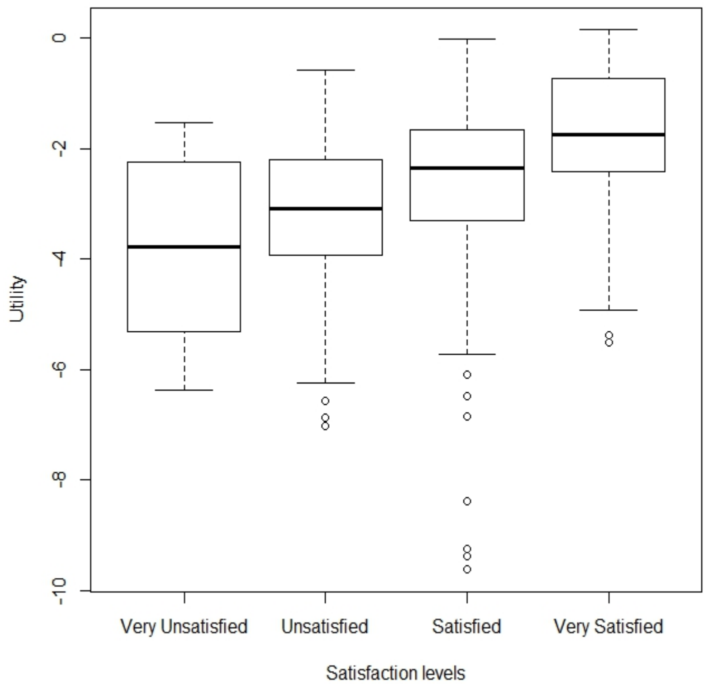


Figure 7 Satisfaction levels and utility of the selected mode

In order to analyse the strength of the association between the utility-based Logsum and the stated satisfaction, the multiple regression (Edwards, 1985) and the one-way ANOVA (Christensen, 2011) approaches have been employed. The multiple linear regression is used to explain the relationship between one continuous dependent variable and two or more independent variables. ANOVA is instead a statistical method typically employed to perform analysis of variance between and within groups.

Employing the multiple regression approach, the analysis of the strength of the association between the Logsum and the stated satisfaction produced a coefficient of determination R2 equal to 0.24 and a multiple correlation coefficient equal to 0.48 for the full sample. The one-way ANOVA analysis, implemented as a confirmation approach, turned out to provide similar results. The correlation between fitted and observed values of the dependent variables is the same as it was for the multiple regression model. The "proportion of variance explained" measure R2 for multiple regression has an ANOVA equivalent, η2 (eta squared), which has in this case a value equal to 0.24.

These results, to some extent, confirm the main hypothesis of the paper. The utility-based Logsum (decision utility) is importantly correlated with the stated satisfaction (a proxy for remembered utility). As expected, the correlation is not perfect but is still significantly higher than the correlation found by Chorus (2012) who used stated choice experiment data and obtained correlations between 0.155 and 0.203.

However, as described previously, our dataset is composed of very different profiles. PhD students have, for instance, lower salaries than professors, and in general have different socio-economic characteristics (e.g. lower car ownership rates, near-free public transport access) and different activity-travel patterns. In addition, the country of residence, as already mentioned, has a huge impact on commuting time and public transport availabilities. Table 13 presents the multiple correlation coefficient for different population categories (in appendix B, a detailed table with the coefficients and their significance tests is included).

To begin with, a high correlation value is observed when the Logsum value is proportional to the satisfaction levels. For instance, someone having several efficient alternatives for commuting and expressing a high satisfaction level would have a high correlation index. A low correlation would indicate that individuals are 1) satisfied by a low workplace accessibility (expressed by the utility-based Logsum) or 2) unsatisfied by a good accessibility. The most striking observation is related to the variation between the residents and the cross-border workers. While commuting satisfaction for Luxembourgish residents is well aligned with their travelling alternatives quality, this does not hold for cross-border workers.

| | | Multiple correlation coefficient |
|---|---|---|
| | Total sample | 0.48 |
| Employment status | PhD students | 0.46 |
| | Professors and researchers | 0.51 |
| | Administrative or technical position | 0.49 |
| Country of residence | Luxembourg | 0.51 |
| | Belgium | 0.12 |
| | France | 0.31 |
| | Germany | 0.1 |
| Socio-demographic characteristics | man | 0.49 |
| | woman | 0.48 |
| | children(no) | 0.45 |
| | children(yes) | 0.54 |
| | Age (<=30) | 0.53 |
| | Age(>30) | 0.47 |
| Commuting mode choice | Car | 0.47 |
| | public transports | 0.44 |
| | Soft modes | 0.19 |

Table 13 Multiple correlation coefficient

The interesting fact is that this dissimilarity is consistent for all three cross-border countries. The quality of the commuting alternatives (expressed by the Logsum value) is far lower, mainly for Germany and Belgium, than the ones of Luxembourgish residents but cross-borders are, on average, “happier” with respect to their resident colleagues. One hypothesis that could be made is that, by stating their general satisfaction, cross-borders workers included other non-travelling related elements such as the advantage of living in their own country (where housing is significantly cheaper), while earning higher Luxembourgish salaries. Similar reasoning is probably applicable for soft modes users who have stated higher satisfaction levels than expected compared to their Logsum value (leading to lower correlation index value). In this case, elements such as the pleasure of being outside, self-contentment of doing a physical activity or having a sustainable behaviour, etc. could have influenced their answers. However, due to a low number of soft modes users this result has to be interpreted with caution.

## 4.6 Conclusion and policy implications

This paper focused on confirming the relation between Random Utility Maximization Logsum and commuting mode choice satisfaction. While random utility theory assumes a perfect correlation between decision utility and remembered utility, some empirical experiments (e.g. Kahneman et al., 1997) showed that the two concepts were in fact different. The discrepancy between ex-ante and ex-post utility evaluation has already been discussed (Abou-Zeid & Ben Akiva, 2012; Ettema et al., 2010; Chorus and de Jong, 2011). However, with the exception of Chorus (2012), the quantification of this difference has received almost no attention from researchers. The importance of this analysis is to assess whether the utility-based satisfaction measure, which is quantifiable, can be a proxy of the travellers' commuting satisfaction, and hence be used for predicting the impact of changes in accessibility, the introduction of new transport services and in general for assessing different TDM strategies.

The travellers' satisfaction responses were collected using a conventional travel survey. These measurements were then correlated with the Logsum that was computed based on parameter estimates obtained from an MNL model. Compared to Chorus (2012) who used stated preferences data and obtained low correlations (between 0.155 and 0.203), our results show that the multiple correlation coefficient in our dataset is significantly higher (0.48). This seems to be in line with Ettema et al. (2010) who formulate the hypothesis that for repeated choices such as commuting, remembered utility will be, after some time, related to decision utility. The Logsum is indeed a good measurement of the satisfaction level but, in our opinion, it is still not fully capable of reproducing the stated satisfaction.

After observing that, at the aggregated level, Logsum and stated commuting satisfaction levels are positively associated, in-depth analysis has shown strong variations among respondents' categories. While association indices are rather stable among socio-demographic classes, this is not anymore the case for the different country of residence and commuting mode choice. Being a resident or not affects the correlation indexes considerably. The cross-border workers having lower Logsum values indicated average satisfaction levels. It seems that, for them, satisfaction is not only related to the trip in itself but also in other elements such as the benefit of living in their own country and having a Luxembourgish salary.

This is also confirmed by the results of the MNL model. Indeed, results show very similar parameters values for PhD students and Professors. However, the ASCs, which represent effects not directly captured by the systematic component, highlight how the car is the most preferred mode. This could be connected with some residential aspects such as the accessibility to public transport infrastructure or, for example, the inability to cycle for very long distances. The introduction of these types of attributes will be object of future research study.

According to Ettema et al. (2010) the goal of policy makers and practitioners should be that of increasing travellers' satisfaction. As shown in this study, decision utility and people evaluations' of their trips do not fully coincide; as a consequence, using standard cost-benefit analysis might be complex from the point of view of policy makers. In addition to classical variables such as travel time, travel cost, number of interchanges, etc. policy makers could systematically take into account soft variables such as comfort, cleanliness, noise level, etc. Kahneman et al. (1997) mentioned that the peak-end rule was, for instance, introducing bias in the evaluation of experience toward the most intense and the end of the considered event. This is particularly interesting regarding the implementation of sustainable transport policies. For instance, when using public transport important delays, strikes and overcrowded services might affect travellers' appreciation more sharply than a high ticket cost. Reliability and consistency in public transport service should constitute important goals of mobility providers. In addition, because the end of the trip (commuting trip or not) will play an important role in the way public transport users evaluate their experience, efforts have to be made to avoid long waiting times (due to red lights, bus bunching, etc.) close to major workplace areas.

Similarly to what Abou-Zeid and Ben-Akiva (2012) suggested for household travel surveys, systematically collecting satisfaction for the travel alternative within cross-sectional travel surveys is a must. The University of Luxembourg, when implementing travel surveys, is adding a single question regarding the home-to-work trip satisfaction. Considering that decision and remembered utility do not totally coincide and that, as pointed out by Ettema et al. (2010), the goal of policy makers is to increase travellers' satisfaction, it is important to collect information on individual trips' satisfaction.

Possible future research directions include: the development of metrics fully capable to reproduce the stated satisfaction; the estimation of the parameters (in the utility function) through a Nested logit and how they could reflect on the Logsum and consequently in the correlation with satisfaction.

## Appendix A.

Chapter 4 highlighted some important determinants of commuting satisfaction such as travel time or travel distance. As already mentioned, commuting satisfaction is seen as an indicator for possible long-term adaptation (mode shift, residential move, quit current job position). Indeed, it is expected that commuters with long lasting negative feelings regarding their home-to-work trip will look for coping strategies.

These long term adaptation strategies might explain why the vast majority of the staff members of the University of Luxembourg are satisfied or very satisfied of their commuting trip. Indeed, the 2016 travel survey shows that only 12% of the entire respondents (N=593) were very unsatisfied and 28% were unsatisfied of the home-to-work journeys. A majority of the Uni staff members has satisfactory (45%) or very satisfactory (14%) feelings regarding the commuting trip.

While the available literature highlights that long commuting times are correlated with less satisfactory feelings, the previous chapter shows that cross-border workers have commuting satisfaction feelings that do not seem to be aligned with their trip characteristic (e.g. time and cost) and their commuting mode availabilities.

This is also confirmed by the 2016 staff travel survey. Of course, as illustrated by Figure 8, on average, the residents are happier than the cross-borders regarding their commuting trip. Average shortest commuting distance & time, the possibility to travel by soft modes explain partly the difference.

However, by comparing the commuting satisfaction for similar trip duration (Figure 9), cross-border and residents have similar ratings despite, for instance, higher public transport costs, the impossibility to commute by soft modes, low public transport accessibility.

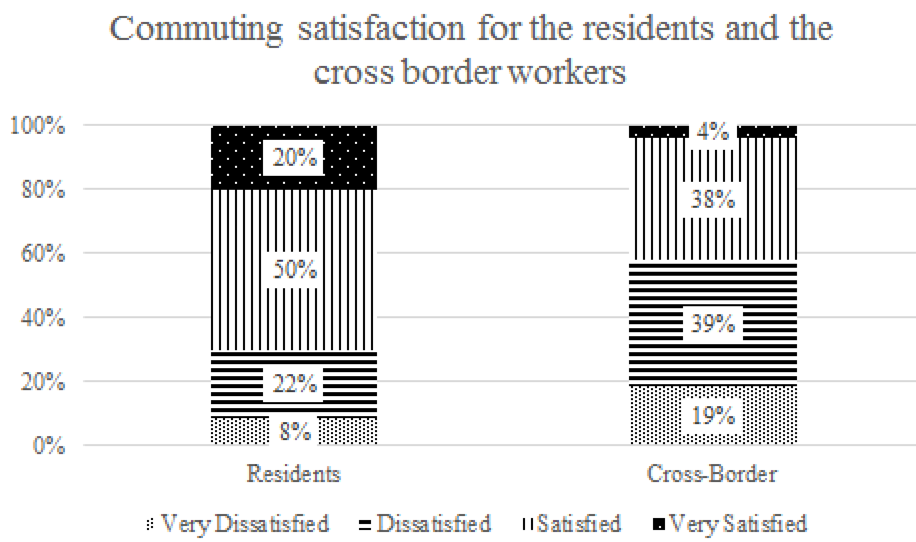


Figure 8 Commuting satisfaction for residents and the cross border workers

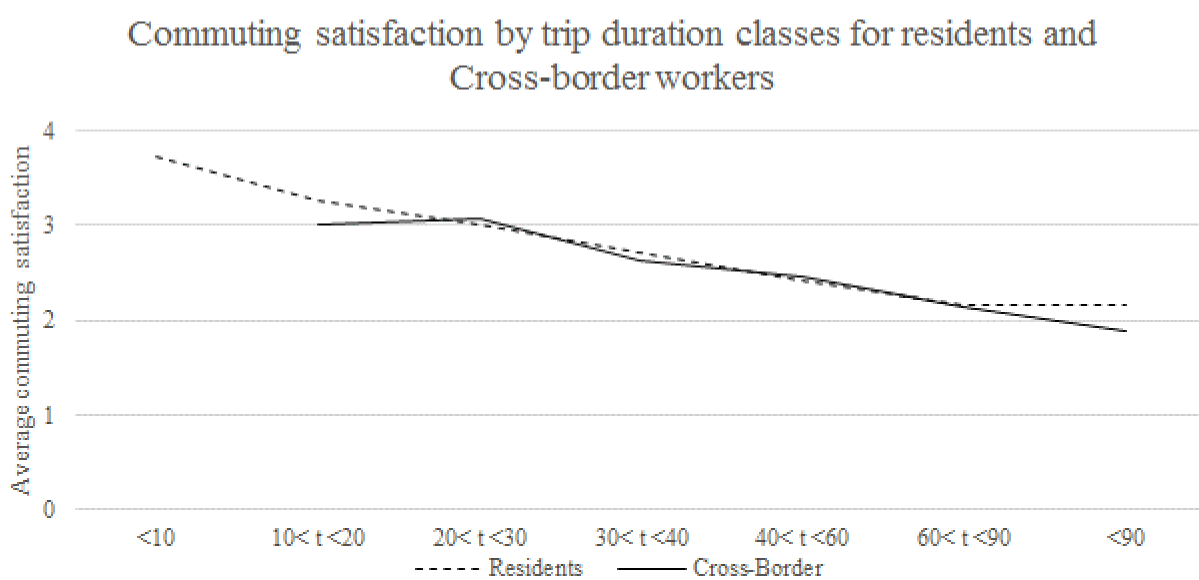


Figure 9 Commuting satisfaction by trip duration classes for residents and Cross-border workers

It is clear that long-term personal decisions such as residential location affect the entire travelling behaviour. While the comparison between commuting satisfaction of cross-border workers and residents is an illustrative example, it is strongly related to Luxembourg case which is very specific.

The objective of the next chapter is to study the impact of residential choices and commuting characteristics on the stated commuting satisfaction. Residential choices are assumed to have both a direct and indirect effect on the commuting satisfaction through the home-to-work trip characteristics.

## Appendix B. Key figures

| Socio-demographic information | | | | | |
|---|---|---|---|---|---|
| Male | 42% | | Professors or researchers | 41% | |
| PhD students | 16% | | Technical or administrative position | 43% | |
| Average age | 39.5 | | Presence of kids younger than 12 in the household | 37% | |
| **Mode choice** | | | | | |
| | Total | Belgium | France | Germany | Luxembourg |
| Car | 55% | 71% | 52% | 58% | 54% |
| Public transport | 39% | 29% | 48% | 42% | 37% |
| Soft modes | 6% | 0% | 0% | 0% | 10% |
| **Mode availability** | | | | | |
| | Total | Belgium | France | Germany | Luxembourg |
| Car | 76% | 86% | 90% | 73% | 73% |
| Public transport | 96% | 93% | 95% | 86% | 100% |
| Soft modes | 44% | 0% | 9% | 0% | 69% |
| **Travel distances and time** | | | | | |
| | Minimum | Maximum | Average | Standard Deviation | |
| Distance (km) | 0.2 | 167.2 | 29.3 | 25.4 | |
| Traveling time (min) | 1.0 | 138.5 | 46.1 | 25.1 | |
| **Work position** | | | | | |
| | Total | Belgium | France | Germany | Luxembourg |
| Technical or administrative position | 43% | 64% | 69% | 37% | 36% |
| PhD students | 16% | 14% | 9% | 23% | 16% |
| Professors or researchers | 41% | 21% | 22% | 40% | 48% |
| **Satisfaction level** | | | | | |
| Average Satisfaction level: | | 2.7 (out of 4) | | | |
| Mode of the satisfaction level | | Satisfied | | | |
| **Satisfaction level by mode** | | | | | |
| | | Car | Public transport | Soft modes | Total |
| Very unsatisfied | | 13% | 5% | 0% | 9% |
| Unsatisfied | | 33% | 28% | 0% | 29% |
| Satisfied | | 38% | 56% | 27% | 44% |
| Very satisfied | | 16% | 11% | 73% | 18% |

Table 14 Key Figures

## Appendix C. Full ANOVA results

| | | Estimate | Std. error | t value | Pr. | MultipleR squared | Multiple Correlation coefficient |
|---|---|---|---|---|---|---|---|
| PHD | Intercept | 2.8756 | 0.4097 | -7.019 | 1.31e-09 *** | 0.22 | 0.46 |
| | Sat2 | 0.7407 | 0.5018 | 1.476 | 0.1445 | | |
| | Sat3 | 0.8872 | 0.4769 | 1.86 | 0.0672 | | |
| | Sat4 | 2.671 | 0.6314 | 4.23 | 7.15e-05 *** | | |
| PROF | Intercept | 2.8556 | 0.4067 | -7.021 | 4.53e-11 *** | 0.26 | 0.51 |
| | Sat2 | 0.4358 | 0.4569 | 0.954 | 0.341396 | | |
| | Sat3 | 1.6419 | 0.4311 | 3.809 | 0.000193 *** | | |
| | Sat4 | 2.5076 | 0.4605 | 5.445 | 1.71e-07 *** | | |
| ADMIN | Intercept | -2.935 | 0.3111 | -9.435 | < 2e-16 *** | 0.24 | 0.49 |
| | Sat2 | 0.4141 | 0.35 | 1.183 | 0.2382 | | |
| | Sat3 | 0.741 | 0.3445 | 2.151 | 0.0328 * | | |
| | Sat4 | 2.3567 | 0.3894 | 6.053 | 7.95e-09 *** | | |
| LUX | Intercept | 2.0475 | 0.2762 | -7.414 | 1.65e-12 *** | 0.26 | 0.51 |
| | Sat2 | 0.4704 | 0.2972 | 1.583 | 0.11461 | | |
| | Sat3 | 1.0998 | 0.2855 | 3.852 | 0.000147 *** | | |
| | Sat4 | 1.7486 | 0.2929 | 5.97 | 7.60e-09 *** | | |
| BE | Intercept | 2.2078 | 0.7796 | -2.832 | 0.00922 ** | 0.01 | 0.12 |
| | Sat2 | 0.4116 | 0.8269 | -0.498 | 0.62313 | | |
| | Sat3 | 0.3942 | 0.8619 | -0.457 | 0.65151 | | |
| | Sat4 | 0.7177 | 1.3503 | -0.532 | 0.59992 | | |
| GE | Intercept | 3.7664 | 0.3253 | -11.579 | <2e-16 *** | 0.01 | 0.1 |
| | Sat2 | 0.145 | 0.3984 | 0.364 | 0.717 | | |
| | Sat3 | 0.0786 | 0.3945 | 0.199 | 0.843 | | |
| | Sat4 | 0.7677 | 0.9758 | 0.787 | 0.434 | | |
| FR | Intercept | -2.486 | 0.3219 | -7.723 | 2.77e-10 *** | 0.01 | 0.31 |
| | Sat2 | 0.2201 | 0.3971 | -0.554 | 0.5817 | | |
| | Sat3 | 0.4311 | 0.4035 | -1.068 | 0.2902 | | |
| | Sat4 | 1.4282 | 0.8517 | 1.677 | 0.0993 . | | |
| CAR | Intercept | -2.7839 | 0.2351 | -11.843 | < 2e-16 *** | 0.22 | 0.47 |
| | Sat2 | 0.6608 | 0.2769 | 2.386 | 0.0178 * | | |
| | Sat3 | 1.2785 | 0.2718 | 4.704 | 4.33e-06 *** | | |
| | Sat4 | 2.2966 | 0.3132 | 7.333 | 3.48e-12 *** | | |
| PT | Intercept | -3.3294 | 0.4889 | -6.811 | 1.70e-10 *** | 0.2 | 0.44 |
| | Sat2 | 0.4111 | 0.528 | 0.779 | 0.4373 | | |
| | Sat3 | 1.3148 | 0.5088 | 2.584 | 0.0106 * | | |
| | Sat4 | 2.6154 | 0.5875 | 4.451 | 1.56e-05 *** | | |
| SOFT | Only Sat3 and Sat4 are present | | | | | 0.36 | 0.19 |
| | Intercept | -0.3295 | 0.2891 | -1.14 | 0.266 | | |
| | Sat4 | 0.3184 | 0.3382 | 0.941 | 0.356 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Male | Intercept | -2.6873 | 0.3763 | -7.141 | 2.15e-11 *** | 0.24 | 0.49 |
| | Sat2 | 0.2303 | 0.4309 | 0.534 | 0.5937 | | |
| | Sat3 | 0.9502 | 0.4061 | 2.339 | 0.0204 * | | |
| | Sat4 | 2.3093 | 0.4346 | 5.314 | 3.11e-07 *** | | |
| Female | Intercept | -3.0126 | 0.263 | -11.455 | < 2e-16 *** | 0.23 | 0.48 |
| | Sat2 | 0.6106 | 0.3 | 2.035 | 0.0429 * | | |
| | Sat3 | 1.3166 | 0.2913 | 4.519 | 9.60e-06 *** | | |
| | Sat4 | 2.536 | 0.3443 | 7.365 | 2.59e-12 *** | | |
| With KIDS | Intercept | -2.8762 | 0.3251 | -8.846 | 1.72e-15 *** | 0.29 | 0.54 |
| | Sat2 | 0.1672 | 0.3764 | 0.444 | 0.65753 | | |
| | Sat3 | 1.1216 | 0.3664 | 3.061 | 0.00259 ** | | |
| | Sat4 | 2.4261 | 0.4023 | 6.03 | 1.12e-08 *** | | |
| No KIDS | Intercept | -2.911 | 0.289 | -10.071 | < 2e-16 *** | 0.21 | 0.45 |
| | Sat2 | 0.6741 | 0.3273 | 2.06 | 0.040371 * | | |
| | Sat3 | 1.2165 | 0.3122 | 3.897 | 0.000123 *** | | |
| | Sat4 | 2.5076 | 0.3527 | 7.11 | 1.02e-11 *** | | |
| Age (<=30) | Intercept | -2.7916 | 0.4959 | -5.63 | 2.98e-07 *** | 0.28 | 0.53 |
| | Sat2 | 0.4374 | 0.5636 | 0.776 | 0.4401 | | |
| | Sat3 | 1.007 | 0.5474 | 1.84 | 0.0698 . | | |
| | Sat4 | 2.5182 | 0.5945 | 4.236 | 6.40e-05 *** | | |
| Age (>30) | Intercept | -2.9186 | 0.2414 | -12.089 | < 2e-16 *** | 0.22 | 0.47 |
| | Sat2 | 0.4818 | 0.2761 | 1.745 | 0.0818 . | | |
| | Sat3 | 1.2186 | 0.2641 | 4.615 | 5.51e-06 *** | | |
| | Sat4 | 2.4441 | 0.299 | 8.175 | 5.29e-15 *** | | |
| FULL SAMPLE | Intercept | -2.8958 | 0.2162 | -13.396 | < 2e-16 *** | 0.24 | 0.48 |
| | Sat2 | 0.4745 | 0.2469 | 1.922 | 0.0553 . | | |
| | Sat3 | 1.1819 | 0.2368 | 4.991 | 8.69e-07 *** | | |
| | Sat4 | 2.473 | 0.2653 | 9.321 | < 2e-16 *** | | |

Table 15 Full ANOVA results

## Acknowledgements

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# 5

# Residential choices and commuting satisfaction

The concept of travelling satisfaction is gaining more and more interest in the transportation field. While increasing travellers' satisfaction should be a goal of policy makers and practitioners, a drop in commuting satisfaction might lead to switch from one mode to another. Objective trip characteristics (time, cost, mode) as well as other elements such as mode attitude, lifestyle, etc. affect travel satisfaction rating. Despite an extensive literature on travel satisfaction determinants, often, the interaction between the studied determinants is overlooked.

The main aim of this chapter is to quantify the impact (both direct and indirect) of residential choices on the home-to-work stated travelling satisfaction. Methodologically, a Discrete Choice Theory approach (via the well-known concept of the utility Logsum) and a Partial Least Square Structural Equation (PLS-SEM) approach have been used and compared. Results of both modelling approaches show that the direct effect of residential choices on commuting satisfaction is negligible compared to individuals' external factors such as trip characteristics. However, using the PLS-SEM approach, indirect effects of residential choices on commuting satisfaction can be quantified.

This chapter is based on the paper:

Sprumont F., Astegiano P., Viti F. Commuting satisfaction and residential choices: Comparative analysis using discrete choice theory and Partial Least Square Structural Equation Modelling. Submitted to Transportation.

## 5.1 Introduction

Since the development of transport economics theory, travelling is described as a derived activity enabling individuals to reach their places of interest, where they plan to perform a certain activity. As underlined by Banister (2008), when travelling, only the benefit of performing the activity at destination is assumed to matter and individuals are expected to minimize their total costs (time, monetary resource, stress level, etc.) when choosing how to perform the trip. However, these intuitive and well-established principles have been challenged by Redmond & Mokhtarian (2001) who concluded that for some individuals the trip in itself could be a source of positive utility. Since then, several studies such as Whalen et al. (2013) or Russell & Mokhtarian (2015) have shown evidence of positive utility for travel time.

The concept of travel liking claims that some travellers are not acting as homo œconomicus trying to reduce the travelling cost but are in fact enjoying their trips. Of course, this behaviour challenges the development of (heavy) transport infrastructures, because travel likers might not be receptive to measures aiming at, among other things, reducing travelling time. While Olsson et al. (2012) found that feelings during the home-to-work trip were mostly positive or neutral, Kahneman et al. (2004) indicate that the work commute was frequently associated with negative feelings. Rating (positively or not) a repetitive commuting behaviour necessarily implies, from the individuals' point of view, an aggregation of the feelings experienced while going to work.

The various elements having an impact on travelling satisfaction are receiving more and more attention from researchers. As pointed out by Mokhtarian & Salomon (2001), travel utility has three main components: the enjoyment of the trip itself, the utility of the activity at destination and the utility of the activities performed while travelling. Controlling the activity at destination is a must and often transport studies dealing with satisfaction analyse single purpose trips (e.g. leisure trips for De Vos & Witlox, 2016). Indeed, an identical train trip might be perceived differently for an individual going to his workplace than for a tourist on vacation.

While a satisfaction increase for public transport mode might, for instance, be due to an improvement of the infrastructure, a satisfaction decrease below a certain threshold can lead to a shift to another mode. This may be the reason why the general stated commuting satisfaction mentioned in Turcottte (2011) or Sprumont et al. (2017) is relatively high whatever the mode. Indeed, travellers may not stick to a travelling option that does not satisfy them except if this travelling option is the only one available.

Commuters are somehow limited in the actions they can implement to increase their home-to-work travelling satisfaction. Workers can relocate their living place, change job location or shift to another mode. More simply, people might also decide to start commuting earlier or opt for a public transport superior class. However, regarding mode shift, Ettema et al. (2016) warn that traveller's expectation of the impact related to mode shift may differ from their actual experience.

While travel mode, travel time and cost are rather intuitively important satisfaction determinants, these elements are interrelated and partly dependent on other elements. For instance, specific personal mode attitude might play a role in selecting the travelling mode from the available options (De Vos et al. 2015). Regarding the commuting trip, the accessibility at the destination is crucial but is often out of control of the commuter even if, as mentioned by Bell (1981), individuals may choose their job partly because of the office location (urban or suburban for instance). Residential choice, which represents a long-term decision, is a key travel behaviour determinant (not only for the commuting trip) for the entire household. As pointed out by Van Wee (2009) residential self-selection process is an important facet to take into account when studying individuals' mobility decisions.

To the best of the authors' knowledge, only De Vos & Witlox (2016), Cao & Ettema (2014) and De Vos et al. (2015) confirmed the effect of specific land-use variables or residential attributes on travel satisfaction feelings. De Vos & Witlox (2016) conclude that people who do not like to travel prefer to live in the urban centre, making it possible to minimize travelling. Cao & Ettema (2014) as well as De Vos et al. (2015) indicate that suburban dwellers have a more positive perception of their trips compared to urban dwellers. Interestingly, Cao & Ettema (2014) indicate that, to some extent, people move into residential areas allowing them to have "happy travelling".

De Vos & Witlox (2016) mentioned the possibility that residential variables (neighbourhood type in their case) might have a bigger indirect rather than direct effect on travel satisfaction. Quantifying both direct and indirect effects of residential choices on commuting satisfaction is the main research question of this paper. First, using Discrete Choice Theory (DCT) approach, the impact of the residential choices on the correlation between the Utility Logsum and the stated satisfaction is assessed. Second, results of a Partial Least Square Structural Equation Model (PLS-SEM) are analysed. The comparison of both DCT and PLS-SEM models is also seen as a valuable scientific contribution.

## 5.2 Literature Review

Starting in 2001 with Mokhtarian & Salomon and Redmond & Mokhtarian, the interest for travel satisfaction determinants has quickly grown. In their paper, Saint-Louis et al. (2014) provided an interesting classification of travelling satisfaction determinants. Internal and external factors (to the decision makers) are distinguished. The first category refers to non-mode-specific attributes and the latter is related to mode-specific attributes such as travelling time and cost, or comfort.

So far, external factors have been the most studied (e.g. Turcotte (2011), Whalen el al., (2013)). Travelling mode, for instance, is probably among the most studied satisfaction determinants. Different studies (e.g. Páez & Whalen (2010), Turcotte (2011)) indicate that soft mode users have the highest satisfaction level while car users have an intermediate satisfaction level and public transport users are the least satisfied. Additionally, other mode-specific characteristics such as travelling time, comfort, cost are directly affecting the way travellers are satisfied (or not) with a trip. Recently, Ettema et al. (2016) point out that while in general car use is associated with higher satisfaction level than public transport, this might not be true for the commuting trip.

As already indicated, travel time does not seem to have a linear negative effect on travelling satisfaction. As recently showed by Russell & Mokhtarian (2014), to most commuters, the travelling time is not always seen as a cost to be minimized or suppressed. Redmond & Mokhtarian (2001) have shown that most workers would prefer to have a shorter commuting time but very few would like to have a commuting time of zero minutes. On the other hand, extreme commuters (Vincent-Geslin & Ravalet, 2013), sometimes because of the (very) high salary obtained, might indicate that they are happy of their travelling conditions despite the very long distances or times travelled. Being employed in a recession period might spill over to positive experience of commuting (Olsson et al, 2013).

Trips characteristics are determined mostly by the location of both the starting point and the ending point. Concerning the destination of the home-to-work trip, some workers may select/avoid a certain job position because of the location of the workplace (Bell, 1981). Concerning the residential choice, Van Wee (2009) underlines that individuals might self-select their residential location for a wide variety of elements.

Proximity to workplace, proximity to specific travel alternatives (train station, bus stop), preferences for specific neighbourhood types, etc. The relationship between residential location and travel behaviour has been covered extensively (see Næss (2005) or Cao et al. (2009) for an exhaustive review) and, for instance, Choocharukul et al. (2008) have shown that the behavioural intention to use the car has a significant influence on residential choice.

Van Wee (2009), who defines self-selection as "the tendency of people to make choices that are relevant for travel behaviour, based on their abilities, needs and preferences", indicates that individuals with a positive stance towards the public transportation system might favour a residential location close to a railway, for instance. This is confirmed by Choocharukul et al. (2008) and more recently by Cao & Ettema (2014) who added that people were moving into a location enabling them to use their preferred travelling options. To our knowledge, Cao & Ettema (2014) were the first to investigate this complex relation between residential choices, travelling satisfaction and mode choices. Whilst they quantified the direct effect of residential preferences on travel satisfaction, our study is aiming at quantifying both the direct and in-direct effect of residential choice.

De Vos & Witlox (2016) did not focus specifically on any mode but showed that general travel attitude (i.e. travel likers versus travel haters) was affecting residential locations. Indeed, they indicate that people who do not like to travel are more likely to live in urban neighbourhoods in order to minimize travel time and distances. To a certain extent, this is similar to Cao & Ettema's (2014) findings who highlight that travel satisfaction (or Satisfaction With Travel (SWT) using their terminology) is lower in high-density neighbourhoods. However, conclusions of both contributions (De Vos & Witlox (2016); Cao & Ettema (2014)) partly diverge with other references (e.g. Paez & Whalen, 2010) ranking travelling mode by their satisfaction level. Indeed, while soft mode are associated with higher satisfaction levels, bike and walk are hardly compatible with travelling distances commonly performed in low-density neighbourhoods.

The number of studies focusing on the complex (inter)relation between travelling satisfaction, trip characteristics and residential choices is still limited and there is room for other empirical studies. The present study will contribute to this scientific debate by providing evidences on the direct/indirect effect of residential choices on commuting satisfaction.

## 5.3 Data & methodology

Using travel survey data from staff members of the University of Luxembourg, the overarching objective of this paper is to quantify both direct and indirect (via the commuting trip) effect of residential choices on commuting satisfaction. In order to verify this research hypothesis with Discrete Choice Theory, an analysis of the correlation between the Logsum of the utility function and the commuters' stated satisfaction will be performed (see Chorus (2012), or Sprumont et al. (2017) for more information on this approach). One assumption of this first methodological step is that inclusion of residential choices variables in a multinomial logit model will positively affect the correlation between sated home-to-work trip satisfaction and the utility Logsum. Additionally, a PLS-SEM approach will be used for validation purposes. It is assumed that PLS-SEM approach will permit to better assess the contribution of the indirect effect of residential choices on stated commuting satisfaction. In this paper, the activity at destination is the same for everyone, i.e. working at the University of Luxembourg. This activity at destination is thus known even if the University staff members can have both positive and negative feelings regarding their professional activity.

## 5.4 Data

The University of Luxembourg (the only one in the country) has been created in 2003 and currently welcomes around 6500 students and 1500 staff members (including PhD students). The first travel survey, which has been implemented between May and June 2012, was seen as a way to establish a benchmark regarding the mobility of the University staff members and to acquire insight into their travelling preferences. At that date, 1095 employees were working for the University and 397 replies were collected suggesting a good representativeness of the sample. After data cleaning, 328 valid surveys were considered for this analysis. Males represent 46% of the respondents while professors & researchers were 39%, PhD students 22% and administrative or technical staff 39%.

However, a specificity is related to the living place of the respondents: only 63.9% of the respondents live within the country of Luxembourg while the remaining share lives in France (10%), Germany (21.2%) and Belgium (4.8%). This situation is due to the higher salary offered in the Grand-Duchy if compared to neighbouring countries, combined with very high residential costs in the country itself. Thus, cross-border commuters prefer benefiting of a high salary in Luxembourg while living in their "home" country, notwithstanding the longer commuting distances and travelling times. While the respondents living in Luxembourg have an average home-to-work distance of 17.7km the cross-border workers have to commute, on average, 45.5 km. In addition, for cross-border workers the probability to benefit of a good public transport connection to work drastically decreases with distance. Cross-border commuters would need, on average, 84 minutes to commute using the public transport system compared to 38 minutes for the people living in Luxembourg (Sprumont et al., 2014). Of course, as indicated by Turcotte (2011) and by Páez & Whalen (2010), such an important difference in the trip characteristics is assumed to impact the commuting satisfaction.

In the travel survey, the question regarding the commuting satisfaction was formulated as follows:

*"Are you globally satisfied by your daily work commute? (If you take into account elements such as the cost, the distance and the stress caused by your home-to-work trips)"*

Respondents could choose between very dissatisfied, dissatisfied, satisfied and very satisfied. The questions regarding the residential choices were phrased as presented below:

"*Which elements influenced your accommodation choice?*

1. *Desire / need to live closer to the university*
2. *The easy access to public transport network*
3. *The large number of shops / services around your accommodation"*
4. *Desire / need to get closer from a friend, a relative*
5. *The pleasant environment around your accommodation*
6. *The attractive price of your accommodation*
7. *The commodities proposed in this accommodation*
8. *Desire / need of independence"*

For each of these elements, respondents had to select between 1) very low influence, 2) low influence, 3) strong influence, 4) very strong influence. All eight elements have been included in explorative models but were not found significant. Information about the first three sub-questions were significant and were taken into account. A higher desire / need to live closer the University is assumed to be correlated with shorter home-to-work distance. Similarly, respondents for those an easy access to a public transport network had a strong impact on their residential location have probably higher chance to use train or bus for the commuting trip. A large number of shop in the direct vicinity of the residence is more likely to happen in urban area. Thus, respondents favouring residential location with many shops in the direct vicinity of their living place have higher probabilities to be urban resident.

## 5.5 Methodology

The aim of this paper is to understand how residential choices affect (directly & indirectly) the commuting satisfaction. In order to verify our hypothesis, we employ both a DCT and a PLS-SEM approach. We will therefore first calibrate a Multinomial Logit (MNL) model with four different model specifications, giving for each of them the degree of correlation between the stated satisfaction and the resulting Logsum, and then we will perform a confirmatory analysis through PLS-SEM (see Figure 10 for the conceptual framework).

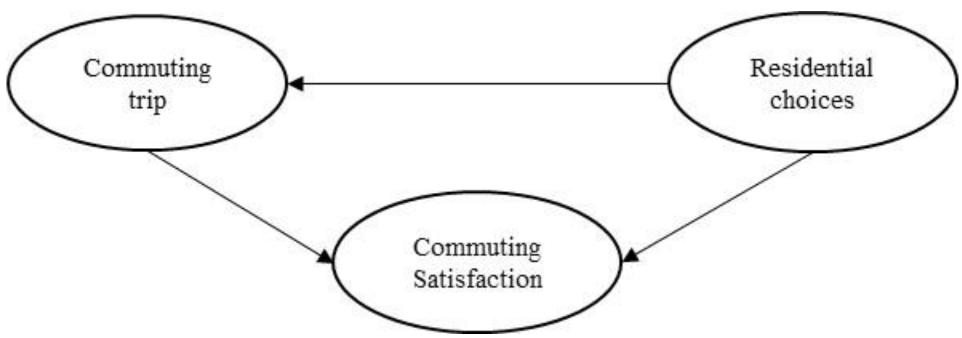


Figure 10 Conceptual model to be tested

*Random Utility Theory: theoretical framework*

Discrete choice analysis is often employed for modelling user choices within a particular context, and is based on the assumption that each person aims at maximizing his/her utility (Ben Akiva & Lerman, 1985). Specifically, it is assumed that each individual, in making a choice, considers all the alternatives that constitute his/her choice set and assigns to them an expected utility. The decision maker will then choose the alternative bearing the highest utility. The utility function is commonly formed by two terms: a systematic part, which depends on a number of attributes, and a residual term, which captures the uncertainty in the model.

Being $U_j^i$, $V_j^i$, $\varepsilon_j^j$ respectively the expected utility, the systematic part and the residual term for individual *i* and alternative *j*, we can express the utility function as:

$$U_j^i = V_j^i + \varepsilon_j^j \quad (1)$$

Where

$$V_j^i = \sum_k \beta_k \; X_{kj}^i \quad (2)$$

In Eq. (2), $\beta_k$ are the weights assigned to the attributes $X_{kj}^i$. In literature, different random utility models were proposed. Among them, the most commonly used is the Multinomial Logit, which is based on the hypothesis that the random residuals are independently and identically Gumbel distributed. Given this assumption, the probability of choosing the alternative j in the choice set m is:

$$p[j] = \frac{\exp(V_j)}{\sum_{i=1}^{m} \exp(V_i)} \quad (3)$$

The logarithm of the denominator in Eq. (3) identifies the Logsum ($LS_{RUM}$) which is the aggregated utility given by the different alternatives considered by the traveller. It can be expressed as:

$$LS_{RUM} = E\left[max_{j=1,\dots J}\left\{U_j\right\}\right] = \int_{\varepsilon}\left[max_{j=1,\dots J}\left\{U_j\right\} \cdot f\left(\varepsilon\right)\right] d\varepsilon = \ln[\sum_{j=1,\dots J} \exp\left(V_j\right)] \quad (4)$$

In transportation, the Logsum function of the utility, as shown in Eq. (4), is often employed as an evaluation measure of the consumer surplus under different transportation planning scenarios. In 2011, Chorus and de Jong have defined the utility Logsum as "the expected maximum utility associated with a traveller's choice set". The correlation analysis between choice stated satisfaction and utility Logsum was implemented for the first time by Chorus (2012) using data from a stated route choice experiment. More recently, Sprumont et al. (2017) have conducted an empirical analysis using travel survey data to investigate the discrepancy between decision utility (Utility Logsum) and aggregated commuting utility (stated satisfaction).

While discrete choice theory presents many advantages (relative theoretical simplicity, forecasting power, etc) this methodology also presents drawbacks. The fact that decision makers are supposed to be fully aware of all the travelling alternatives and their characteristics is a major concern. Such issues have led researchers to try new methodologies such as Structural Equation Modelling (SEM). SEM approach, which is now becoming popular in travel behaviour analysis (Golob, 2003), was initially developed by marketing analysts.

*Structural Equation Modelling*

The use of SEM in this paper has been motivated by suggestions proposed by Van Wee (2009), Cao & Ettema (2014) and De Vos & Witlox (2016) who mentioned that SEM could be an appropriate methodology to assess the complex (inter)relation between residential choices, trip characteristics and satisfaction.

SEM, a second-generation technique in relation to regression analysis (Lowry & Gaskin, 2014), was originally developed in the 1970's (Jöreskog, 1973), and is potentially seen by Hair (2012) as the most influential and important statistical development in the social sciences recently. Van Acker et al. (2007) highlight the possibility to use latent variable and to quantify both direct and indirect effects of one factor on another as the main advantages of SEM.

When developing a SEM with latent variables, Coltman et al. (2008) strongly recommend justifying the use of either formative or reflective latent variables. As indicated by Lowry & Gaskin (2014) or Chang et al. (2016) the main reason for selecting a reflective or a formative latent variable is the causality direction between the indicators and the construct. To the best of our knowledge, in the transport field, only Banerjee and Hine (2016) have opted for formative latent variables (in combination with reflective latent variables) and have provided a justification for this important conceptual choice. Jarvis et al. (2003) or Lowry & Gaskin (2014) provide useful guidelines on how to select the nature of the latent constructs i.e. either reflectively or formatively. While the causality direction is crucial, the characteristics of the nature, the interchangeability of the indicators must be taken into account as well when developing the measurement models. In this paper, the methodological reasons for selecting formative latent variables were the different facets covered by some indicators (the socio-demographic latent variables cover job position, having kids, and gender information) and the causality direction of the constructs (from the indicators to the latent variables).

While selecting formative or reflective measurement model is conceptually important, this choice has another major methodological impact. The majority of the transport studies that have used SEM have specifically used Covariance-Based SEM (CB-SEM). Similarly, to what Coltman et al. (2008) observed in marketing sciences, travel behaviour analysts mostly assume that their measurement models are reflective. However, when using formative measurement models many studies such Hair et al. (2011), Lowry & Gaskin (2014), Banerjee & Hine (2016) have strongly recommended to use Partial Least Square SEM (PLS-SEM). Useful rules of thumb for selection PLS-SEM or CB-SEM are provided by Hair et al. (2011) (table 2, p144).

PLS-SEM or CB-SEM both present specific advantages and drawbacks that are not identical for both approaches (Hair et al., 2011). Finally, Hair, Ringle and Sarstedt (2012) indicated that PLS-SEM and CB-SEM differ in term of estimation objectives and philosophy. PLS-SEM approach seeks to maximize the explained variance of the dependent latent constructs (R2), CB-SEM approach is maximizing the difference between the model-implied covariance matrix and the sample covariance matrix (Hair et al., 2011; 2012).

## 5.6 Data Analysis and results

### 5.6.1 Descriptive analysis

As suggested by Figure 11 and Figure 12, the commuting distance and the commuting mode choice do seem to play an important role in how people rate their trip satisfaction. The two figures support the conclusion of Abou Zeid (2009) on the positive feelings related to soft mode use, the intermediate satisfaction for public transport users and the lower satisfaction for car commuters.

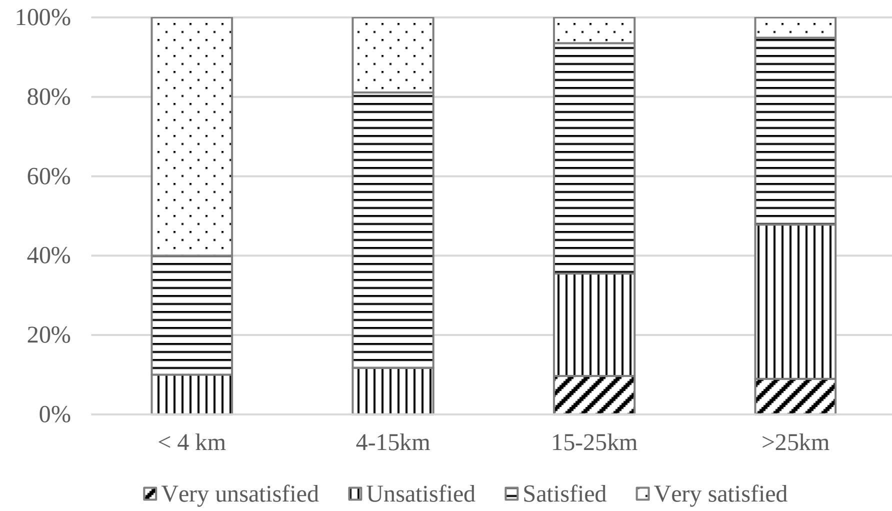


Figure 11 Commuting satisfaction and travelling distances

However, by observing these two figures it is not clear how the commuting distance and the selected commuting mode interact. Indeed, perhaps commuting distance is only indirectly influencing commuting satisfaction by discouraging soft and public modes usage.

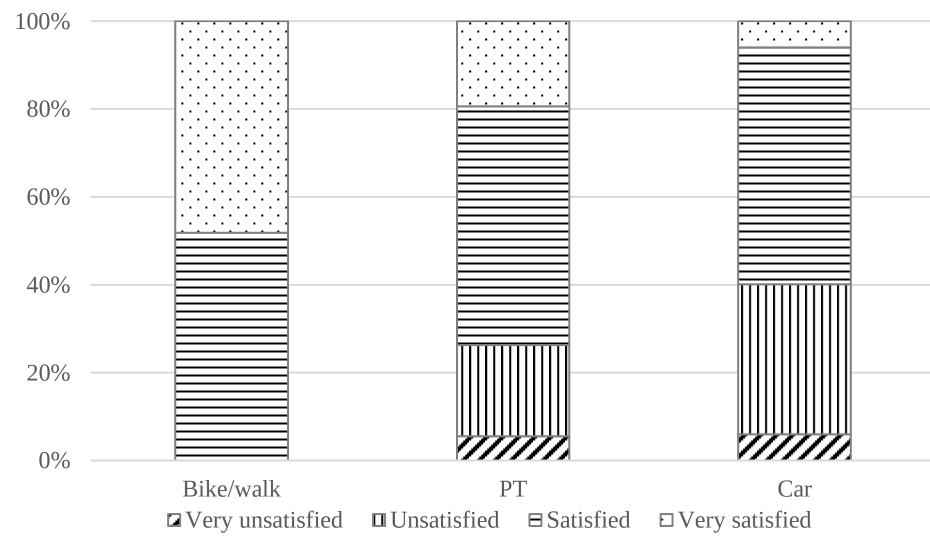


Figure 12 Commuting satisfaction and mode choice

Concerning the effect of residential choices, one would expect for instance that respondents who claim "the proximity of the university had a very high influence" live closer to the university than those who do not. Indeed, the average home-to-work distance for the two categories reaches respectively 17.5km and 32.9km. Respondents that favoured home-workplace proximity have a modal split of 39% for Car, 42% for PT and 19% for soft modes while the modal split is 57% for car 40% for PT and 3% for soft modes for university staff members that did not choose their residence based on the home-to-work distance. Thus, intuitively, because short commuting distance can be performed with soft modes, which are associated with more travelling satisfaction, the stated travelling satisfaction is more important (3.1 versus 2.6 on a 4 scale point) for respondents who selected their home place location partly based on their home-to-work distance.

Following the same line of reasoning, those that favoured the proximity to public transport infrastructure when selecting their residential place tend to use more the public transport system than those who don't (64.5% vs. 28%). Such simple but striking modal shift variation is in line with the conclusions of De Vos & Witlox (2016) concerning the self-selection hypothesis. Obviously, people have selected a residential area that would allow them to commute using the travel alternative that they prefer. Since in our sample PT use is associated with a higher satisfaction compared to car use, the respondents that have selected their home location close to public transport infrastructure are, on average 9% more satisfied of their commuting trip. Among respondents who indicated being satisfied of their commuting trip, 74% mention that access to public infrastructure was important or very important.

Even though time consuming, the construction of the database prior to the MNL model estimation might provide insightful information. For all travel alternatives, thus including the selected one, travel time, travel cost as well as mode availabilities were computed for all. It has been previously indicated that, on average, commuting satisfaction was higher for soft modes than public transport and car. This holds true mainly for individuals that have access to three travelling modes, which is not always the case. As discussed by Mokhtarian & Salomon (2001), walkers or cyclists may be "happy commuters" as long as their mode was actually chosen and not constrained. Mode-captivity, whatever the mode considered, may reduce the positive attitude towards this alternative. While 60% of the car drivers are satisfied or very satisfied, the percentage decreases to 45% for those having exclusive access to car. Following the same reasoning for public transport, while 74% of PT users declare to have positive stance regarding their commuting trip the share falls to 61% for university staff members having access to public transport alone. It's thus clear that whatever mode the travellers use, if it is the only accessible mode the stated travelling satisfaction will be lower.

## 5.7 Multinomial Logit model calibration

The previous section, devoted to the descriptive analysis, provides insightful information on the relation between travel mode characteristics, residential choices and commuting satisfaction. However, so far, no direct or indirect effects on commuting satisfaction have been presented neither the relation between trip characteristics, residential variables and socio-demographic variables.

The very first step is to develop several MNL models and verify the estimated values for some parameters. Then, for each model specification the utility Logsum is computed and an ANOVA analysis is performed to assess the degree of correlation. Chorus (2012) was the first to implement this methodology but did not find important correlations (0.155 to 0.203) between utility Logsum and stated satisfaction. Recently Sprumont et al. (2017) have found, using the same methodology but with travel survey data, relatively high correlation (multiple correlation coefficient for the total sample = 0.48) value between the home-to-work stated satisfaction and the utility Logsum. As indicated earlier, the hypothesis is that the inclusion of residential choices variables will increase the correlation level between stated satisfaction and Logsum Utility.

In our model calibration, we considered three modes of transport: Car, Public Transport (PT) and Soft modes (walking and cycling). We then considered the employment status (either "PhD student" or "Other") and two residential attributes: the proximity to work and the proximity to public transport. We tested also other information such as gender, income, shop availability, etc. but they turned to be not significant in the model estimation.

Summarizing, the systematic part of the utility function (Eq. 2) has different specifications: the “Base model” contains trip characteristics such as travel time and travel cost; the “Work position model” contains, together with the trip characteristics, the employment status; the “Residential model” includes attributes such as proximity to work and accessibility to public transport.

The models were calibrated through the travel behaviour analysis software Biogeme (Bierlaire, 2003) and the results are summarized in Table 16. The Alternative Specific Constant (ASC) reflects the mean of the difference between the residual terms, that is the difference in the utility of an alternative i from j when everything else is equal; PhD is instead a dummy variable that takes value 1 if the user is a PhD student and zero otherwise. The proximity to public transport and to work are two dummy variables that take value 1 if the user declares to be influenced by these two attributes in his/her residential choice and zero otherwise. The PhD attribute turned to be significant only for Car alternative and as it is shown in Table 16 the utility of Car decreases with being a PhD (not surprisingly considering that the majority of the PhD students live in Luxembourg and commute by public transport and soft modes). Finally, the proximity to PT has a positive effect for people that commute by Public Transport. Looking at the goodness of fit of the models, we can notice how an increase in the number of parameters slightly increase the value of the rho-square which is stable around the value of 0.2.

| | Model1 (Base) | Model2 (Base+PhD Dummy) | Model3 (Base+ Residential) | Model4 (Full model) |
|---|---|---|---|---|
| ASC_CAR | 0.00 Fixed | 0.00 Fixed | 0.00 Fixed | 0.00 Fixed |
| ASC_PT | -0.567<br>(0.270) | -0.746<br>(0.289) | -1.19<br>(0.406) | -1.31<br>(0.418) |
| ASC_SOFT | -1.12<br>(0.341) | -1.31<br>(0.358) | -0.772<br>(0.398 | -0.934<br>(0.416) |
| B_COST | -0.106<br>(0.0446) | -0.104<br>(0.0444) | -0.114<br>(0.0470) | -0.114<br>(0.0470) |
| B_TIME | -0.0509<br>(0.0116) | -0.0488<br>(0.0116) | -0.0485<br>(0.0120) | -0.0471<br>(0.0120) |
| B_PHD_CAR | | -0.749<br>(0.392) | | -0.586<br>(0.405) |
| B_PTprox_PT | | | 1.21<br>(0.328) | 1.16<br>(0.331) |
| B_Work_CAR | | | 0.563<br>(0.390) | 0.536<br>(0.394) |
| | | | | |
| Rho-square | 0.199 | 0.202 | 0.226 | 0.226 |
| Final loglikelihood | -167.527 | -165.733 | -159.667 | -158.637 |

Table 16 Estimation results

Given these results we performed an ANOVA analysis between the stated satisfaction and the utility Logsum for each of these four models in order to understand whether residential attributes could increase the correlation magnitude. Because the stated commuting satisfaction is a four-point likert scale and the Logsum is continuous, standard correlation indicators could not be used (as opposed to Chorus, 2012). The one-way ANOVA (Christensen, 2011) approach has been employed to measure the association magnitude between the stated satisfaction and the utility Logsum for the four different model specifications.

The multiple correlation coefficient for each model is:

1. Model 1 (Base): 0,349
2. Model 2 (Base+PhD dummy variable): 0.338
3. Model 3 (Base+ Residential): 0.376
4. Model 4 (Full model): 0.369

It can be observed that the models in which both trip characteristics and residential attributes are included have the highest degree of correlation. However, this value is only marginally higher than the "Base" model. Therefore, we confirm that a correlation exists between the stated satisfaction for the commuting trip and the Logsum function of utility. However, this correlation is mostly influenced by travel time and travel cost. As a consequence, our initial intuition in which we assumed a potential influence of the residential attributes in the commuting choice is partially confirmed, although the resulting impact is lower than we expected.

## 5.8 Partial Least Square Structural Equation Model

Figure 13 shows the main results of the PLS-SEM implemented with SmartPLS software (Ringle et al., 2005). The entire model results can be found in table 17.

A quick look at the two different measurement models inform us on the relative weights of each indicator within each of the two latent variables. For instance, within the "Proximity preference" latent variable, the "Proximity for shops" outer weight is not statistically different from zero. In such context, Hair et al. (2011) have suggested that indicators without a significant outer weight might be kept if the outer loadings are significant or for verifying a research hypothesis.

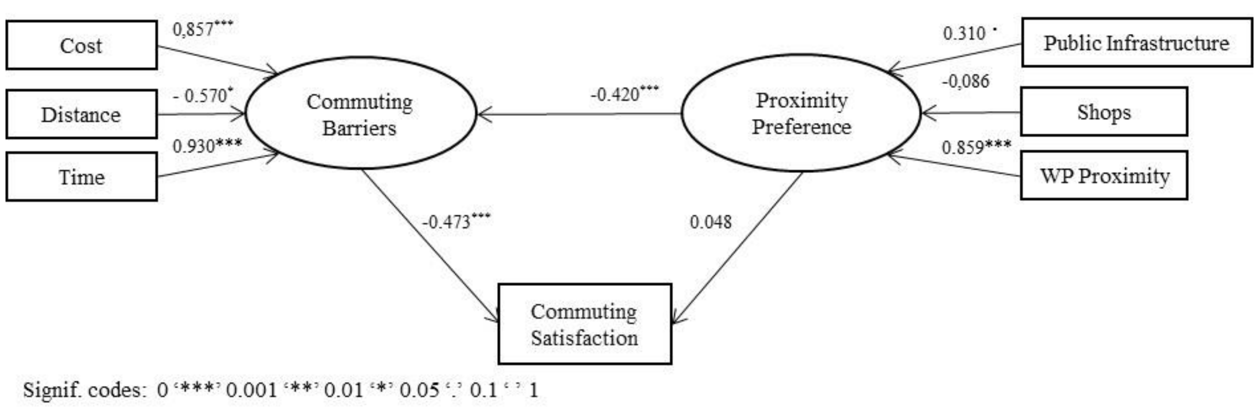


Figure 13 Model results Path coefficients and outer weights

| Path Coefficients | Original Sample | T Stat. | P Values | |
|---|---|---|---|---|
| Proximity preferences -> Commuting satisfaction | 0,048 | 0,88 | 0,380 | |
| Proximity preferences -> Commuting Barriers | -0,42 | 10,03 | 0,000 | *** |
| Commuting Barriers-> Commuting satisfaction | -0,47 | 9,54 | 0,000 | *** |
| **Total Effects** | **Original Sample** | **T Stat.** | **P Values** | |
| Proximity preferences -> Commuting satisfaction | 0,25 | 4,46 | 0,000 | *** |
| Proximity preferences -> Commuting Barriers | -0,42 | 10,03 | 0,000 | *** |
| Commuting Barriers-> Commuting satisfaction | -0,47 | 9,54 | 0,000 | *** |
| **Outer Loadings** | **Original Sample** | **T Stat.** | **P Values** | |
| Cost -> Commuting Barriers | 0,78 | 10,21 | 0,000 | *** |
| PT Proximity -> Proximity preferences | 0,60 | 4,21 | 0,000 | *** |
| Shops Proximity -> Proximity preferences | 0,17 | 1,29 | 0,198 | |
| Workplace Proximity -> Proximity preferences | 0,96 | 19,55 | 0,000 | *** |
| Distance -> Commuting Barriers | 0,81 | 16,23 | 0,000 | *** |
| Time -> Commuting Barriers | 0,85 | 13,38 | 0,000 | *** |
| **Outer Weights** | **Original Sample** | **T Stat.** | **P Values** | |
| Cost -> Commuting Barriers | 0,86 | 5,01 | 0,000 | *** |
| PT Proximity -> Proximity preferences | 0,31 | 1,65 | 0,099 | . |
| Shops Proximity -> Proximity preferences | -0,09 | 0,63 | 0,530 | |
| Workplace Proximity -> Proximity preferences | 0,86 | 7,54 | 0,000 | *** |
| Distance -> Commuting Barriers | -0,57 | 2,39 | 0,017 | * |
| Time -> Commuting Barriers | 0,93 | 6,08 | 0,000 | *** |
| **Quality Criteria** | | | | |
| R2 Commuting Barriers | 0,176 | | | |
| R2 Commuting Satisfaction | 0,245 | | | |
| SRMR | 0,046 | | | |
| Chi-Square | 45,515 | | | |

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 17 SEM full results

When analyzing the PLS-SEM outputs, the results provided by the structural model (path coefficient between the latent variables) are usually the most interesting. In our case, the analysis of the structural model provides a straightforward response to the research question. Indeed, the "Commuting barriers" latent variable is the only one directly influencing commuting satisfaction. The “Preference for Proximity” latent variable does not have a direct impact significantly different from zero.

The indirect effect of “Proximity preferences” through commuting trip is both non-negligible and significant. This seems to indicate that the residential preferences of the University staff members does not directly affect their stated satisfaction but it affects their commuting trip characteristics (or commuting barriers), which in turn are affecting the home to work satisfaction

In order to assess the impact of categorical variables such as gender or job position the implementation of a PLS-Multi Group Analysis (or PLS-MGA) is mandatory (Andreev et al.,2009; Lowry and Gaskin, 2014).Three socio-demographic variables have been tested in the Multi Group Analysis namely having a children (under 12 and living in the household), gender and job position (being yes or no a PhD student).

Effect of child presence in the household on Path Coefficients

<table>
<tr><th></th><th>Path Coefficients-diff ( | NoChildren - Children |)</th><th>p-Value</th></tr>
<tr><td>Proximity preferences -> Commuting satisfaction</td><td>0,069</td><td>0,719</td></tr>
<tr><td>Proximity preferences -> Commuting Barriers</td><td>0,040</td><td>0,660</td></tr>
<tr><td>Commuting Barriers-> Commuting satisfaction</td><td>0,050</td><td>0,693</td></tr>
</table>

Effect on gender on Path Coefficients

<table>
<tr><th></th><th>Path Coefficients-diff ( | Males - Female |)</th><th>p-Value</th></tr>
<tr><td>Proximity preferences -> Commuting satisfaction</td><td>0,078</td><td>0,253</td></tr>
<tr><td>Proximity preferences -> Commuting Barriers</td><td>0,001</td><td>0,492</td></tr>
<tr><td>Commuting Barriers-> Commuting satisfaction</td><td>0,098</td><td>0,170</td></tr>
</table>

Effect of job position (Phd student) on Path Coefficients

<table>
<tr><th></th><th>Path Coefficients-diff ( | PhD - No_PHD |)</th><th>p-Value</th></tr>
<tr><td>Proximity preferences -> Commuting satisfaction</td><td>0,085</td><td>0,698</td></tr>
<tr><td>Proximity preferences -> Commuting Barriers</td><td>0,130</td><td>0,899</td></tr>
<tr><td>Commuting Barriers-> Commuting satisfaction</td><td>0,069</td><td>0,715</td></tr>
</table>

Table 18 Multi Group analysis results for the path coefficient difference and significance

Concerning goodness-of-fit criteria, the R2 value for commuting satisfaction reaches 0.245. Hair et al. (2011) indicate that in marketing research such value would be seen as weak. However, in transportation, due to the lack of comparison point and because of the relative data complexity this result is seen as non-negligible. In addition, Banerjee and Hine (2016), using PLS-SEM in travel behaviour analysis, presented a model where the highest R2 for endogenous variables was reaching 0.28, hence comparable with ours.

Considering the available data and the research question, using PLS-SEM approach enabled us to provide a straightforward answer to the main research question of this work. While with the model specification that has been used, residential preferences (“preference for proximity”) do not influence directly the commuting satisfaction, the total effect (direct + indirect) is non-negligible and significant. The commuting trip characteristics ("commuting barriers") have a strong and significant direct effect on commuting satisfaction but are importantly influenced by individual's residential preferences.

## 5.9 Methodological considerations

While the development of a discrete choice model provides interesting information such as the value of time (VoT) or the relative importance of a variable compared to another via the estimated parameters, this approach may not be the most suitable to analyze both direct and indirect effect of (latent) variables on a dependent variable (i.e. the commuting satisfaction). While discrete choice models allow the estimation of modal share and thus permit to forecast modal shifts based on a developed scenario, their relative important data needs (related to the non-chosen alternatives) may be seen as an important constraint. Structural Equation Modelling approaches do not require additional data than the one provided by staff travel survey respondents. Off-the-shelf softwares such as SmartPLS (Ringle et al., 2005) are drastically reducing the technical / coding skills needed to run models of varying complexity.

Regarding the specific research question related to the possible impact of residential preferences on the way commuters rate their travel satisfaction, both methodologies provided useful information but PLS-SEM provided a more straightforward response with less efforts.

The question regarding the usefullness of both methodologies for adressing a specific question remains unanswered. In this specific case, PLS-SEM has been used as a second approach to corroborate unexpected results of the first methodology. Being totally different, the quality of DCT and PLS-SEM outputs cannot be subject to any kind of ranking. However, in this case study, using only PLS-SEM allowed to save time in terms of data collection and model development.

## 5.10 Conclusion

In this study we investigated the influence, both direct and indirect, of the residential choices on the stated commuting satisfaction using discrete choice theory and a PLS-SEM approach.

The discrete choice approach allowed to demonstrate that the commuting satisfaction and the utility logsum are positively correlated. This shows that, despite a growing interest for travel satisfaction concepts, utility theory will remain useful to approximate commuters' satisfaction. More precisely, the utility Logsum is an interesting metric allowing travel behavior analysts to approximate the positive or negative feeling associated with a specific trip. In addition to providing a measure of the transport accessibility at one place, it has been showed that its (co)relation with satisfaction is truly valuable. However, because adding residential choices in the model was only leading to a minor correlation increase, our research hypothesis is only partially supported.

On the other hand both methodologies (DCT and PLS-SEM) suggested that the direct effect of residential choices on commuting satisfaction was weak to not existent. However, the PLS-SEM (Figure 13) approach shows an indirect effect of these residential attributes on the stated satisfaction. Residential attributes influence the commuting trip directly and this fact is then reflected in the coefficient that expresses the degree of influence of the trip characteristics on the stated satisfaction.

Regarding policy implications, our results are providing additional legitimacy to urban planners to develop dense and mixed-used neighbourhoods. Indeed, as also shown by Ettema et al. (2016), soft mode use is associated with higher level of Subjective Well Being (SWB) and switching from car to soft mode is leading to long lasting improved SWB. Whilst in dense area such as urban center enable soft mode use is associated with high SWB level and healh benefit (de Hartog et al., 2010) some individuals might still favour suburban location allowing them to use their preferred travelling option which is often the car.

The debate on the commuting satisfaction determinants remains complex. This scientific contribution calls for additional research to be done in the field. The limitation of standard employer-based travel survey is certainly reaching its limits in terms of usage. To better understand how people perceived their trips specific surveying method have to be improved and, as shown in this study, the methodology has to be selected carefully.

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# 6

# The effect of the activity pattern on commuting mode choice

Chapters 4 and 5 provided detailed information on commuting satisfaction and the effect of long-term decisions such as residential choices on how people perceive their home-to-work journey. Additionally chapters 3, 4 and 5 were relying exclusively on travel surveys implemented at the University of Luxembourg, which focussed on the commuting trips. However, commuting represents about a quarter of all trips made by workers, but it influences their entire daily mobility.

While cross-sectional data set have proven to be useful in order to study commuting satisfaction determinant or mode choice forecasting, additional data was needed in order to analyse the modification of the activity pattern due to the staff member's workplace relocation. Analysing commuting tours, rather than commuting trips solely, permits a better understanding of mobility behaviour, especially mode choice. In particular, the complexity of activity patterns can be an impediment to using public or active commuting modes. We explore this question using travel diary data from employees of the University of Luxembourg and a Partial Least Square Structural Equation Modelling (PLS-SEM) approach.

Scheduled in July 2015, the closure of Walferdange campus of the University of Luxembourg was seen as a unique opportunity to collect travel diary information before and after a workplace relocation. Accordingly, in May and June 2015, a web-based multi-day survey had been implemented. After data cleaning, 51 staff members of the University of Luxembourg provided 15 days of consecutive (or 2 times 7 days) information (activity duration, location and type as well as trip duration and mode). More than 700 days of information have been collected and nearly 3000 activities encoded.

Our explorative analysis suggests that the activity pattern of workers strongly influences their car use behaviour for commuting. We also show that socio-demographic characteristics do not directly influence car use but that their indirect effect is non-negligible. Our results suggest that employer based solutions to reduce car use, that would focus only on the commuting trip (parking pricing, support in season tickets, etc.) without considering socio-demographic characteristics and the other daily activities of employees may underperform.

The implementation of the second travel diary data collection phase and the associated methodological issues will be described in the next chapter. Before being able to understand how a firm relocation can affect the activity-travel behaviour, a solid understanding of the relation between the activity pattern and mode choice is needed. So far, the previous chapters have focused on the commuting trip and, thus, analyse how the activity pattern is influencing the commuting tours was seen as a natural transition.

This chapter is based on the paper:

Sprumont F., Viti F., Cornelis E., Caruso G. Commuting tours, activity pattern and car use behaviour: a PLS-SEM approach. To be (re-)submitted to Journal of Transport Geography.

## 6.1 Introduction

Sustainable mobility is nowadays an established goal for urban planners and policy makers (e.g. European Commission, 2011), with the objective to curb greenhouse gases and pollutants emissions without impeding individuals to carry out their many daily activities. Sustainable mobility measures include reductions in travel demand, especially trip lengths and private car use to the benefit of public transport modes and more generally of greater efficiency in the transportation system (Banister, 2008).

Commuting is a critical part of the daily activity-travel chain and represents a significant share of the total number of trips undertaken by individuals. Therefore, it remains a major focus of sustainable mobility policies because of its repetitive pattern in time and space, compared to the heterogeneity of other activity-travel sequences, and its impact on traffic congestion and delays road users experience on a daily basis.

In addition, commuting lends itself to mobility management solutions by employers, such as parking pricing at job locations, support for seasonal transit passes, etc. with potentially higher impact on sustainability in a region than the unilateral decisions made by individual households. In this respect, large employers have a paramount role because of the number of employees they represent and their potentially higher lobbying capacity to improve the supply and functioning of transport infrastructures in a given region. It is therefore important to better understand the commuting mode choice from employees of large companies and eventually, in the longer run, the effectiveness of transport solutions offered to their employees.

While commuting may represent an important policy lever, one cannot narrowly focus on this trip and neglect how it is embedded within, and constrained by, a daily chain of activities. Complex activity patterns may well impede some workers in using public transport or active modes for commuting despite, for example, having to perform a short home-work distance. Activities like picking up or dropping off a child at school, or performing daily shopping before returning home, may constrain the mode choice of some individuals, hence making him or her highly irresponsive to transport policy measures. If sustainable mobility measures are very strict in discouraging the use of the car but ignore the daily constraints and activities of individuals, they may result in an overall loss of commuting satisfaction rather than obtaining a shift toward more sustainable mobility alternatives (Sprumont et al., 2017). In many cases, analysing the daily sequence of activities can help to understand commuting behaviour and choices that would appear non-rational when focusing only on the commuting trip.

We hypothesize that analysing and understanding the impact of (complex) activity-travel patterns is a necessary step to understand travel behaviour in general, and more specifically commuting mode choice (see e.g. Adler and Ben-Akiva, 1979, Bhat, 1999, Timmermans et al., 2003; or Krygsman et al., 2007). Motivated by the above rationale, we provide in this study insights into the decision process that relates commuting mode choice to both work and non-work activities performed by workers. In particular, we provide an analysis of the role of activity chains on car use for commuting, by looking at the specific case of a large employer, the University of Luxembourg. Our analysis relies on a travel diary multi-day survey and a Structural Equation Modelling (SEM) approach (Golob, 2003). More specifically, we apply a Partial Least Square SEM (PLS-SEM), which is a relatively novel and unexplored methodology in travel behaviour analysis. It allows one to reveal latent effects and complex interactions between activity patterns, the employees' characteristics and their decision to use their car or not for commuting purposes. We control for variabilities at destination since we consider a single employer.

## 6.2 Assumptions and methods

### 6.2.1 Commuting and activity chains: knowledge gaps and assumptions

Mode choice is known to be a complex decision process where a large number of parameters interact and influence the decision maker, consciously or not (De Witte et al., 2013; Zhou, 2012; Van Acker et al., 2007). While land use and the physical environment are among the most studied determinants (e.g. Ewing and Cervero, 2010), other factors, such as lifestyle, perceptions, habits and trip chaining received less attention from an empirical perspective. Among the knowledge gaps identified by De Witte et al. (2013), habits and trip chaining factors would typically need further investigation since their impact on travel mode is usually found to be significant. The latter will be the main focus of this paper.

As emphasised by Timmermans et al. (2003), during a typical day, individuals make many decisions related to their activity pattern and their travelling behaviour: people choose how many activities they want to perform (within tours or not), where, at what time, for how long and the mode they will use to reach their activity locations. The combination of scheduling, alternative destinations and modes lead to many possible decisions every day. Individuals partly routinize portions of these decisions, limiting the general complexity of both activity patterns and travel behaviour (Gärling and Axhausen, 2003). For instance, Schlich and Axhausen (2003) indicate that the locations visited in a day have very limited spatial variability and that 90% of all trips reach a common pool of eight locations. On the other hand, empirical studies reported that a rather small share of all daily activity-travel patterns are restricted to the simple Home-Work-Home trips sequence, while the largest majority include at least one more chained activity (Viti et al., 2010).

Trip-chaining can be described as the action of going from an activity location to a different activity location without going back to an anchor location, typically home or work. For instance, a person can make a total of four separate trips but only two are chained: e.g. dropping children on the way to work and stopping at a shop on the way home. More generally, the entire daily activity pattern can be considered as a determinant of the mode choice for every specific tour or trip.

Workers combine commuting (work-related trip) and non-work-related trips in order to avoid time loss and thus maximize their global utility. By adding one or several activities before and/or after work, individuals and households can save up to 15% of their total travel time (Vande Walle et al., 2006). The fact that the starting time of many non-work related activities coincides with after-work hours is an additional reason for trip chaining (Vande Walle et al., 2006). While the advantage of trip chaining is clear for individuals and households, the impact on the aggregated travel demand of a transport system remains an object of discussion. Wang (2015) claims that trip chaining could lead to a reduced overall number of Vehicle-Miles Travelled (VMT) but also to heavier peak hour traffic congestion. An increasing complexity of trip chains (or tours) is associated with higher car-dependence levels since the flexibility and convenience of a car is perceived as an asset to perform non-simple activity sequences (Ye et al. 2007). Vande Walle et al. (2006) show that, despite the availability of public transport for a majority of single trips, a “missing link” could lead an individual to perform all the trips in a chain by car. An individual might have a good home-work public connection but the fact that this individual performs a non-work activity, not accessible by public transport, will force him/her to use the car. Overall, we see that using a single trip perspective or even a work tour perspective for understanding commuting mode choice may lead to underestimating the use of cars or it may lead to setting up inadequate sustainability measures.

McGuckin et al. (2005) indicate that public transport commuters are almost twice as likely to make direct home-work-home trips. They also observe that long-distance commuters have a higher propensity to include a non-work related activity before going back home. Lee and McNally (2003) highlight the possibility for individuals to perform activities opportunistically, e.g. short activities included within their commuting. Krygsman et al. (2007) and Ye et al. (2007) have reported important interdependencies between travel and activity decisions and in particular intricate causalities between mode choice and trip chaining patterns. Ye et al. (2007) suggest that the complexity of the activity pattern tends to drive the mode choice rather than the opposite. Krygsman et al. (2007) also claim that the mode decision is most often adjusted to decisions related to the choice of trip chaining (and not the opposite). However, the literature is not particularly clear on this interaction and further empirical analysis is clearly needed. As Wang (2015) recently pointed out, whilst the relation between the individuals' activity pattern and their travelling behaviour has been studied for more than three decades, results often remain non-consistent or conflictual, which can partially be associated with reduced size samples and limited spatial coverage.

In addition to the relationship between mode choice and trip chaining, socio-demographic characteristics also influence both the daily activity pattern of individuals and their mode choice, hence a third dimension needs to be added in order to correctly understand the link between commuting behaviour and activity chains. The effect of individual characteristics on trip mode choice has been an integral part of discrete choice modelling approaches (see e.g. Bhat, 1999). Socio-demographic effects on activity patterns have also been well studied. Already in 1979, Adler and Ben-Akiva highlighted the importance of the socio-economic characteristics of households as a trip-chaining determinant. Household structure, as noted by Hensher & Reyes (2000) and Kuppam & Pendyala (2001), affects the number of undertaken activities. Having dependent children could lead, for instance, to more caring activities and therefore to performing more complex daily activity patterns, especially for single parents. Kuppam and Pendyala (2001) or McGuckin et al. (2005) also show that caring activities are more often performed by women than men.

To sum up, car use for commuting, which is the target of employer-based sustainable transport policies, is impacted by both the individual's activity pattern and the socio-demographic characteristics. Our objective is to measure the impact of Activity Pattern Complexity (APC) on Car Use (CU) while controlling the impact of individual characteristics in the relation between APC and CU. Given the above literature, we consider car use to be directly and sensibly influenced by the activity pattern complexity. We further aim to check if some individual characteristics influence the magnitude of the relation between Activity Pattern Complexity and Car Use.

Assuming causal relationships is always a risky process, especially in travel choice behaviour (see e.g. Ye et al., 2007) and our approach should still be seen as explorative, in particular when considering the size and specificity of the dataset available. In addition, causalities may be fallacious in the case of omitted variables, selection bias, model misspecification, or simultaneity (see e.g. Antonakis, 2010). Nevertheless, we still believe that the present study can be used as valuable first step to obtain a more general assessment of the relation between APC and CU.

In this paper, we decided to consider a Structural Equation Modelling (SEM) approach, and more particularly the PLS-SEM approach given the power of this methodology of dealing with relatively small databases and with highly correlated measurable factors. The variables CU and APC are in fact complex constructs each bearing multiple dimensions and inherent complex relations. They can therefore be considered and dealt with in SEM as latent variables derived from a set of simpler measured indicators (Xi). In the following we describe more in detail SEM theory, and in particular the class of Partial Least Square SEM, which has been adopted in this study.

### 6.2.2 Structural Equation Modelling (SEM)

Structural Equation Modelling (SEM) is a technique developed in the 70's (Jöreskog, 1973), and recently adopted in the transportation field (Golob, 2003). SEM is seen by Hair et al. (2012) as possibly the most important and influential statistical development in social sciences in recent years. According to Van Acker et al. (2007), the main advantage of SEM compared to classical regression analysis is the possibility to work with latent variables and to quantify direct and indirect effects of one factor on another. The latter is particularly important for us, given our research objectives and the knowledge gaps identified previously.

As underlined by Coltman et al. (2008), when using latent variables with SEM, researchers should always explicitly justify their choice for using reflective or formative measurement models. In our study, the direction of the causality, i.e. from the indicator to the latent construct, and the various themes covered by some indicators for a single latent construct were important elements that led us to opt for formative constructs. Our choice is also in line with the recent work of Banerjee and Hine (2016), who stress that, while most transport studies using SEM have used reflective constructs, many constructs in the transport domain remain strictly formative.

Because categorical or ordinal indicators should not be used to develop latent construct, assessing the effect of socio-demographic variables (gender, job position, etc.) imply the implementation of a Multi-Group Analysis (MGA). This step permits to compare the difference and its significance for path coefficients, outer weights and loading, latent constructs' R variation and so on (Andreev et al.,2009; Lowry and Gaskin, 2014).

Coltman et al. (2008) as well as Jarvis et al. (2003) provide useful guidelines on how to select the nature of the latent constructs, i.e. either reflectively or formatively. For instance, they indicate that the direction of the causality, and the nature and interchangeability of the indicators must be taken into account when developing a measurement model. While a high (positive) correlation between indicators of a reflective construct is seen as desirable, this is not the case in formative constructs, where indicators do not necessarily cover the same theme. Coltman et al. (2008) warn researchers about using an inappropriate measurement model since it can undermine the content validity of the construct, while Jarvis et al. (2003) point out that an inadequate measurement model can, in some circumstances, lead to inflate unstandardised estimates by 400% or deflate them by 80%. Recently, however, Chang et al. (2016) showed that the use of reflective models for constructs that could have been modelled in a formative way is not systematically leading to dramatic differences in results.

Using formative or reflective latent constructs is conceptually important but also bears important operational implications for model estimation. Indeed, while Covariance-Based SEM (or CB-SEM) is the standard approach to estimate models with reflective latent variables, Partial Least Square SEM (PLS-SEM) is strongly recommended when formative constructs are adopted (Hair et al., 2011, and Lowry & Gaskin, 2014). To the best of our knowledge, Banerjee and Hine (2016) are the sole authors to have applied PLS-SEM in the transport field. The research objectives, the available data and the use of formative measurement models are the reasons for employing PLS-SEM in this study.

There are advantages and drawbacks to both CB-SEM and PLS-SEM (see Hair et al., 2011, for an exhaustive comparison). While CB-SEM aims at minimising the difference between the sample covariance matrix and the model-implied covariance matrix, PLS-SEM aims at maximising the explained variance of the dependent latent constructs (Hair et al., 2011; 2012).

## 6.3 Case Study and data description

### 6.3.1 Sample

In May and June 2015, a multi-day survey was conducted on 51 workers of the University of Luxembourg. The University is a large employer and recently moved to a new location (Belval), which triggered reflection on a series of new sustainable transport measures (parking pricing, corporate car-sharing and carpooling services). This work is part of a larger study aimed at understanding the behaviour of employees in order to fine tune the employer-based mobility measures to be implemented at the new place of work (future comparative multi-day surveys are foreseen and will be analysed in future studies). The respondents provided information regarding their activity pattern (activity location, type and duration) and associated trips (travel mode, trip duration). They also provided basic information regarding their socio-demographic status (age, gender, work position…).

Although the sample is limited (because of the travel diary approach, which entails important efforts for the respondents), it provides 705 days of information and includes 2793 activities with their associated trips. Since we focus on the relation between activity patterns and commuting behaviour, only weekdays where a work activity has been described were kept for further analysis. Our analysis therefore includes 444 days and a total of 1850 activities (see appendix A for descriptive statistics of the sample).

In order to avoid incorrect generalisation of our results, we must stress two specificities of our case study. First, all respondents were working on a peri-urban campus (Walferdange), located 8 km North of Luxembourg City. Our results are likely to differ in case of a more central job location where more opportunities for activities are available. Second, our respondents are highly qualified and mostly international. The education level of the respondents is high (45% have a PhD degree, 37% a Master degree) and it is important to consider that almost half of the employees in Luxembourg cross a national border as part of their commute. Hence, the quantification of the results of our analysis cannot be generalised countrywide, but we believe that the main conclusions generally hold and are actually not limited to the case of Luxembourg.

### 6.3.2 Commuting modes and distances

Overall 57% of the respondents commute by car (driving or as passengers) as main mode of transport (i.e. the one with highest travel time when a sequence of modes is reported) and 39% by public transportation, which is in line with the university population as estimated by the 2012 university staff travel survey (Sprumont et al., 2014). In 90 % of the cases, the first travelling mode of the day (when individuals leave home) is the main mode for the day. This amounts to 95% for cars, suggesting a strong dependency on the car for many activities.

For the 444 days described by the individuals, 150 “drop-off, pick up someone” activities were encoded. For 81% of these activities the associated mode is the car. In addition, 80% of the dropping off/picking up activities were performed by respondents living with a child, highlighting the important effect of household responsibilities on travel behaviour.

The commuting mode is, to a certain extent, related to commuting distance. On average, car commuters have a home-work distance of 33 km; public transport users have a 30 km trip length and the active modes (foot, bike) users have a commuting distance of 2.9 and 9.5km, respectively. Given the size of the country and its attractiveness, a differentiation must be made between cross-border and internal commuters. The shortest commute (one way) for a cross-border commuter reaches 32.6km (average 63.0km for 16 individuals) whilst the longest commute for internals reaches only 34km (average 15.9km for 35 individuals). However, in our sample, car use difference between the cross-border and internal workers is not important (54.3% for respondents living in Luxembourg versus 62.5% for cross-border workers) compared to what is observed at the national level (Carpentier et al., 2009).

### 6.3.3 Activity chains

Figure 14 (inspired by Drevon et al., 2016) shows that, within the 444 workdays described by the respondents, 19% of the daily activity patterns were "Home-Work-Home", which is in line with previous studies done in other countries (e.g. Viti et al., 2010). After aggregating all the other activity types ("Shopping", "Drop-off / pick-up someone", "Eat", "Learning activity", "Leisure, sport, culture", "Personal business", "Other", "Walking, riding, etc.", "Visit to family or friends") into a "Other Activity" class, a total number of 86 daily activity sequences from the simple Home-Work-Home to more complex ones is obtained. Figure 14 shows the 11 most recurring activity patterns. They represent 71% of the total activity chains of the respondents.

Among those 11 most recurring activity chains, only three include activities that are performed outside the commuting tours. In total, 9.5% of the total activities are performed outside commuting tours, either in the morning or in the evening. Activity chains of cross-border and internal workers are significantly distinct. For instance, 20.3% of the daily activity chains described by the people living in Luxembourg are "H-W-H-A-H" whilst this sequence accounts for only 4.8% when considering the cross-border workers only. This indicates that people living closer to their workplace tend to go back to their home before engaging in a new activity. This finding is somewhat complementary to the behaviour reported by McGuckin et al. (2005), who observed that long-distance commuters were often taking part in an activity before going back home. Cross-border workers also perform a higher number of different activity chains. Indeed, 72 different daily activity chains have been described by the cross-border respondents against 39 for the respondents living in Luxembourg. Drevon et al. (2016) showed that 54 % of the cross-borders workers of Luxembourg have a simple Home-Work-Home activity pattern.

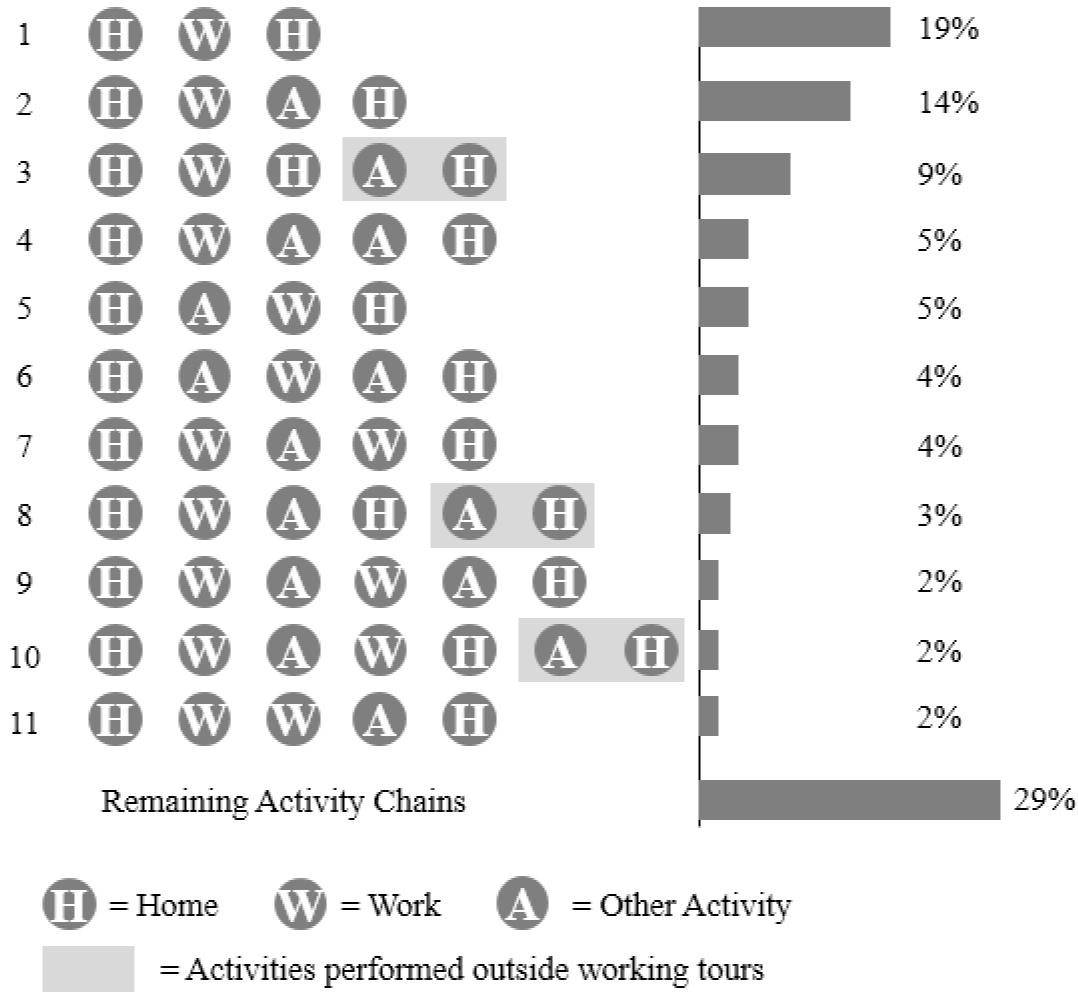


Figure 14 The 11 most recurring activity chains

### 6.3.4 Activities scheduling and sequencing

Figure 15 shows the aggregated activity profile of all the described days. This graph indicates the respondents' share engaged in three activity types (Home – Work – other Activity) along the day. The small peak around 8:00 is very likely due to the dropping-off activity, while the one around 12:00 is both due to lunch-break trips, and in some cases, to picking-up activities (e.g. children finish their classes at 12:00 on Wednesdays in Belgium, while on Tuesdays and Thursdays in Luxembourg). Finally, the larger spread of the distribution of non-work related activities in the late afternoon is due to both activities done within the home-work chain and due to activities done after returning back home.

Our analysis so far was limited to show aggregated and descriptive statistics, thus hiding intra-personal variation of daily activity patterns. As an example, while 86 different activity chains were encoded for the 444 days, individuals have on average 5.9 different daily activity patterns on 8.7 described days on average per person. The smallest intra-personal variation corresponds to an individual who performed only two different daily activity sequences in the two-week observation period (H-W-H and H-A-W-H). The largest intra-personal variability corresponds to an individual who performed a different daily activity pattern for each of the transcribed working days. This is in line with findings reported by Schlich and Axhausen (2003) who concluded that travel behaviour (or alternatively activity pattern) is neither totally a routine nor totally variable.

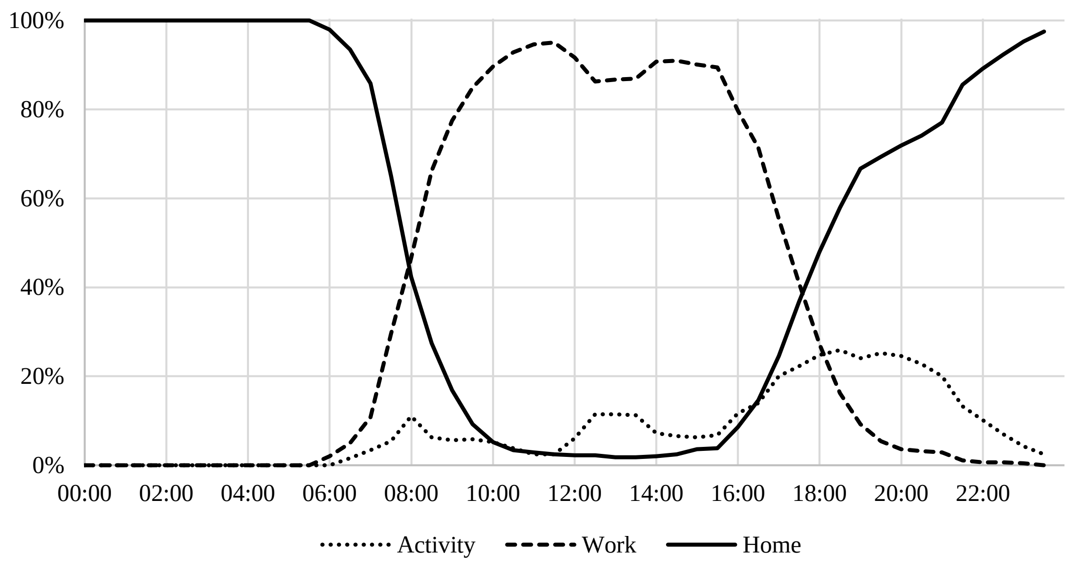


Figure 15 Aggregated activity profile (N=444) of the surveyed population

## 6.4 PLS-SEM Model

The previous section was devoted to a descriptive analysis of the data and provided an understanding of the relation between socio-demographic variables, activity pattern and travel mode choice. We now turn to quantifying the direct effect of the activity pattern complexity (APC) on car use (CU) while controlling the effects of individuals' characteristics. As explained previously APC and CU are considered as latent constructs and the PLS-SEM methodology is selected in order to analyse the assumed relation. Because all respondents, except one, have a driving licence and 80% of them have the possibility to commute by car every day or nearly every day, Car Use (CU) considers car trips done either as a driver or as a passenger.

While the objective of the paper is to quantify the magnitude between mode choice (more specifically car in our case) and the complexity of the individual's activity pattern, we acknowledge that our conceptual framework and the subsequent models focus on a limited set of mode choice determinants. Especially, due to data limitation and because they were under focus by other authors, we do not include effects of land use and neighbourhood context. Van Wee (2009) suggests self-selection between residential choice and mode choice. Schwanen and Mokhtarian (2005) and more recently De Vos et al. (2012) have shown that not only physical residential contexts matter but also attitudes and preferences toward certain types of living environments affect travel behaviour. Retrieving these attitudes was out of our data collection scope however.

### 6.4.1 Model specification

We initially consider each working day provided by each respondent as the basic unit for our analysis. The 444 days are processed as if they were provided by 444 distinct individuals. We acknowledge this assumption neglects any longitudinal or panel data correlations, but these cannot be reasonably assessed with the limited sample at our disposal. In support of our choice, we highlight that intra-personal variability concerning daily activity behaviour is important in our dataset and has also been reported in other studies (e.g. Moiseeva et al., 2014). In addition, Multi-Group Analysis (MGA) allows to partially assess the effect individual characteristics (in this case; gender, if respondents are PhD students or not and the presence of child under 12 living in the household). Finally, in appendix C, interested readers will find modelling results using, as a data set, an average daily behaviour for the 51 respondents. This supplementary analysis relying on 51 data points (instead of 444), one per participants, shows that the path coefficients and the outer weight and loading remain very stable. However, as expected because of the very limited data set the significance level is decreasing. These various precautions compensates at least partly for the assumption of independence across days by providing a control on individuals.

As part of this research, we have tested many model specifications and checked the robustness of the interpretations reported here against these specifications. In particular, we have tested different measurement models for each of the latent constructs, using different combinations of the indicators at our disposal within the survey. The indicators used are described in Table 19. We report only one specification of the measurement models and of the structural model, i.e. the one derived from our assumptions and literature. The number of measurement indicators is kept to a minimum for each latent variable in order not to conflict with our limited sample size.

| **Indicators used for the Car Use latent variable (CU)** | **VIF All** | **VIF Work** | **VIF Mixed** |
|---|---|---|---|
| Distcar: total distance travelled by car over the whole day(All), or within work tour (Work, Mixed) | 1.266 | 1,2 | 1,2 |
| CarTrips: number of trips done by car over the whole day(All), or within work tour (Work, Mixed) | 1.550 | 1,304 | 1,304 |
| TotDiffModes: number of different modes used over the whole day(All), or within work tour (Work, Mixed) | 1.640 | 1,211 | 1,211 |
| **Indicators used for the Activity Pattern latent variable (AP)** | | | |
| TotActivity : number of activities performed over the whole day (All, Mixed) or within work tour (Work) | 11.326 | 8,138 | 11,326 |
| NWorkActi: number of non-work activities performed over the whole day (All, Mixed) or within work tour (Work) | 12.118 | 8,556 | 12.118 |
| NWorkActiTi: time spent on non-work-activities over the whole day (All, Mixed) or within work tour (Work) | 1.820 | 1,577 | 1.820 |
| LateActi: number of activities started after 7PM of the considered day | 1.464 | 1,179 | 1.464 |
| **Indicators for the Socio-Demographic Latent variable (SD)** | | | |
| Age: age of the respondent | 1.192 | 1,192 | 1,192 |
| Gender: gender of the respondent | 1.042 | 1,042 | 1,042 |
| Child: if household of respondent has a child under 12 | 1.153 | 1,153 | 1,153 |

Table 19 Measurement indicators and VIF for each PLS-SEM model variation

Nevertheless, we present two variations of the specified model in order to better contrast the effect of activity patterns complexity (APC) on commuting mode choice compared to a more general (multi-activity) travel mode choice. In the two specification cases, the 444 records of the sample dataset are considered, but the indicators used for creating the Car Use (CU) construct are handled differently and the activity chains are differentiated based on whether or not they are part of a work tour. We believe this is a rather innovative way of deciphering the source of car use behaviour within different types of chains.

Our first data specification (ALL) takes into account the entire daily activity pattern and all the travel performed during a specific day. Car use is analysed for the whole day, independent of the activity performed. This model aims at quantifying the effect of the daily activity pattern on the daily car use behaviour of workers over the entire day. The second data specification (WORK) takes into account the activities and travel behaviour observed during the work tour only, thus, in-between the departure from home to work and the arrival back home. Taking the examples in Figure 14, the grey-shaded parts of the activity chains are neglected. This model aims at more precisely quantifying the effect of the work-tour activity pattern on the commuting mode choice, which is the core of our interrogation and employer-based mobility measures.

## 6.5 Results

Our models were run using SmartPLS, a standalone PLS-SEM software (Ringle et al., 2005). As suggested in Hair et al. (2011) and implemented in Banerjee and Hine (2016), bootstrapping with 5000 samples was used in order to obtain the significance levels of the path coefficients, outer weights and outer loadings.

When estimating composite scores with PLS software, modellers have to choose between Mode A (correlation weights) or Mode B (regression weights). While PLS literature (see Hair et al., 2011 for instance) has suggested to use Mode B with formative latent variables, recent work led us to select Mode A. Indeed, recent and advanced simulation work of Becker et al. (2013) shows that Mode A was more suited with limited sample size and existing collinearity.

Descriptive statistics for each of the measured indicators, and how they vary between the two implementations are provided in Appendix B. In order to check for multi-collinearity, we follow Diamantopoulos et al (2008), Hair et al. (2011) and Banerjee and Hine (2016) and report Variance Inflation Factors (VIF) in Table 20 for all measured indicators contributing to the three latent variables for each of the two model variations. CarUseRate presents the highest VIF values (3.033 & 2.977) probably because of its existing correlation with CarUse (0.79). The other VIF values range between 1.018 and 2.743, which is well below common cut-off values (Diamantopoulos et al. (2008) indicate a “commonly accepted cut-off value of VIF >10”).

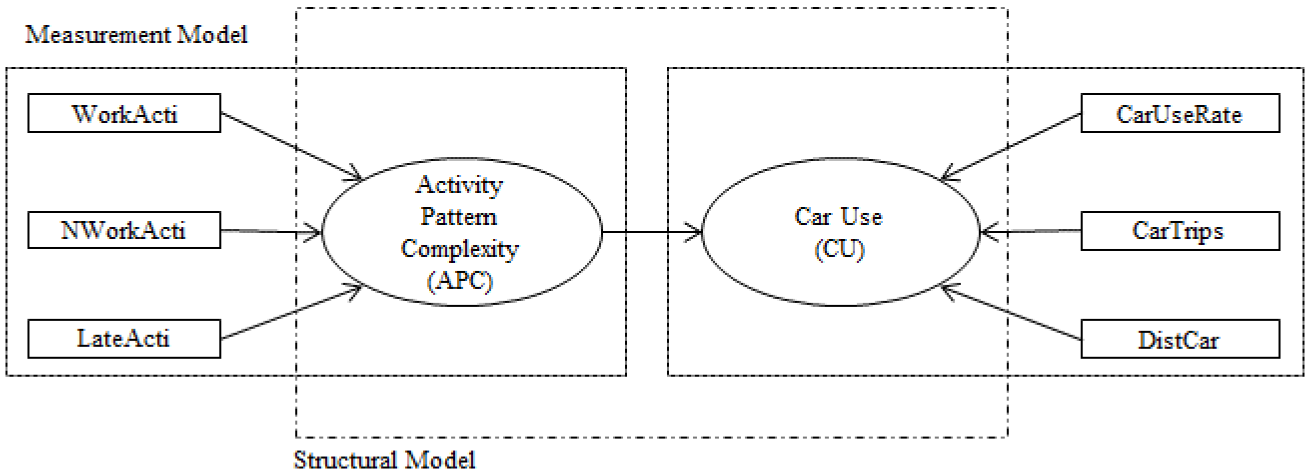


Figure 16 PLS-SEM model

| **Path Coefficients** | WorkTour | | | All | | |
|---|---|---|---|---|---|---|
| | Original Sample | T Stat. | P Values | Original Sample | T Stat. | P Values |
| Activity Pattern Complexity -> Car Use | 0,526 | 18,65 | *** | 0,484 | 18,73 | *** |
| **Outer Loadings** | | | | | | |
| | Original Sample | T Stat. | P Values | Original Sample | T Stat. | P Values |
| CarUsage -> CU | 0,990 | 165,266 | *** | 0,995 | 20,6 | *** |
| CarUseRate -> CU | 0,855 | 37,309 | *** | 0,832 | 15,54 | *** |
| DistCar -> CU | 0,480 | 8,098 | *** | 0,458 | 5,595 | *** |
| LateActi -> ACP | 0,480 | 4,804 | *** | 0,649 | 8,241 | *** |
| NWorkActi -> ACP | 0,963 | 48,670 | *** | 0,971 | 19,22 | *** |
| WorkActi -> ACP | 0,427 | 4,561 | *** | 0,300 | 2,892 | ** |
| **Outer Weights** | | | | | | |
| | Original Sample | T Stat. | P Values | Original Sample | T Stat. | P Values |
| CarUsage -> CU | 0,840 | 16,577 | *** | 0,911 | 9,855 | *** |
| CarUseRate -> CU | 0,147 | 3,283 | *** | 0,064 | 0,86 | |
| DistCar -> CU | 0,090 | 1,753 | . | 0,087 | 1,289 | |
| LateActi -> APC | 0,168 | 2,526 | * | 0,195 | 2,799 | ** |
| NWorkActi -> APC | 0,853 | 16,227 | *** | 0,846 | 12,22 | *** |
| WorkActi -> APC | 0,230 | 2,896 | ** | 0,173 | 2,048 | * |
| Validity Criteria | | | | | | |
| $R^2$ Car use Behavior | | 0,277 | | | 0,235 | |
| SRMR | | 0,117 | | | 0,129 | |
| Discriminant validity (Fornell-Larcker Critertion) | | 0,526 | | | 0,484 | |

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 20 Fit and coefficient estimates of each PLS-SEM model variation.

Overall, our models have a reasonable fit, the WORK model with a standardised root mean residual (SRMR) of 0.117 while Ringle et al. (2015) indicate that a value of 0.1 or below is good. We also find relative consistency of the outer loadings and weights across the 2 models, again with a higher significance when only the commuting part of the travel is considered (WORK models). We see from reported R2 coefficients that car use is reasonably well explained as soon as we have a correspondence between the activities and the travel considered: all activities and the entire daily travel mode in the ALL model (R2=0.235) or work tour activities and commuting mode in the WORK model (R2=0.277. Overall, our R2 values are moderate, yet equivalent compared to similar studies that attempted to retrieve travel behaviour (Banerjee & Hine, 2016).

Looking at the structural path coefficient estimate (AP to CU), we find a strong link between activity patterns complexity and car use, with very significant coefficients for the 2 models. This is an important first result, which is fully in line with previous literature about the importance of activity chains in understanding mode choice. Comparing the WORK and ALL implementations of the model, we find a decrease of the Activity Pattern effect on car use (from 0.526 to 0.484), which is expected since after returning home and finishing a working-tour, respondents have the possibility to use another mode cycling/walking for to perform local activities.

We must obviously refine these results by looking at the meaning of our Activity Pattern Complexity (APC) and Car Use (CU) constructs. Among the three assumed indicators for APC, the number (NWorkActi and WorkActi) of activities are significant but performing activities after 7PM (LateActi) does not clearly contribute to the path coefficients (Low weight values and limited significance for the WorkTour model). This is essentially due to the fact that working tours described by the participants do contains many activities starting at 7pm or later (average of 0.11 for the work-tour data specification as opposed to 0.89 for the entire daily activity sequence).

Among the three assumed indicators for CU, the distance travelled by car (DistCar) is less important than the number of trips performed by car (CarTrips) and the share of car trips compared to the total trips (CarUseRate). Once again, the weight values differ between the two models suggest a potential behavioural shift after or before the working tour.

**Effect on gender on Path Coefficients**

| | WorkTour | | All | |
|---|---|---|---|---|
| | Total Effects-diff ( \| Female - Male \|) | p-Value | Total Effects-diff ( \| Female - Male \|) | p-Value |
| Activity Pattern Complexity --> Car Use | 0,168 | 0,004 | 0,154 | 0,048 |

**Effect of job position (Phd student) on Path Coefficients**

| | WorkTour | | All | |
|---|---|---|---|---|
| | Total Effects-diff ( \| PhD - NoPhD \|) | p-Value | Total Effects-diff ( \| PhD - NoPhD \|) | p-Value |
| Activity Pattern Complexity --> Car Use | 0,157 | 0,996 | 0,087 | 0,917 |

**Effect of being a resident or a cross-border on Path Coefficients**

| | WorkTour | | All | |
|---|---|---|---|---|
| | Total Effects-diff ( \| Residents - Cross-Border \|) | p-Value | Total Effects-diff ( \| Residents - Cross-Border \|) | p-Value |
| Activity Pattern Complexity --> Car Use | 0,226 | 1,000 | 0,386 | 0,565 |

Table 21 Multi-Group Analysis. Effect of Socio-demo information on the path coefficient

While the effect of the Activity-Pattern Complexity on Car Use has already been well described, little has been said on the effect of socio demographic variables on this relation. The Multi-Group analysis performed in SmartPLS (Ringle et al., 2015) enabled us to verify the effect of several individual characteristics (in this case; being a PhD or not, being a male or a female, being a cross-border worker or a resident). The gender dummy variable is significant (MGA probability value lower than 0.05 or higher than 0.95) both for the "WorkTour" and the "All" data specification. This indicates that the effect of activity pattern complexity is, statistically significantly, stronger for females than for males. Interestingly, the effect of APC on CU is also significantly stronger for PhD students than for all types of job positions but this effect is not significant for the "All" data specification. Finally, the path coefficient is statistically stronger for participants living in Luxembourg than for the cross border workers.

While the relation between the activity pattern complexity and car use is important for the general population, some individual characteristics imply a weakened or a strengthened effect. This suggests that individual characteristics must be taken into account in commuting behaviour not for their own sake, but only because they imply a particular activity pattern. To some extent, this is aligned with Lu et al. (1999) and Kuppam et al. (2001) or Van Acker et al. (2007) who all stress the importance of socio-demographic variables and their interaction with activity pattern, residential choices, etc.

## 6.6 Conclusions

We have provided some new hints into the decision process that relates commuting mode choice and the activity chains performed by workers of a large employer, the University of Luxembourg. The PLS-SEM approach we applied, which has seldom been used to date in travel behaviour modelling, and the variation of our data specifications allowed us to confirm results from the literature that car use behaviour is strongly affected by the daily activity pattern of workers. In addition, we found that the choice of the car for commuting is affected by activity patterns not only within, but also outside working tours. Individual activity patterns themselves depend on socio-demographic characteristics, especially when their effect on commuting is under focus. Socio-demographic information and activity patterns cannot therefore be ignored when devising employer-based transport policy measures. Although the development and the assessment of classical pull and push-type of mobility management measures have been extensively described (Rye, 2002; Van Malderen et al., 2012), these measures are generally focusing on sub-portions of individual activity patterns without embracing their overall complexity.

In line with Ye et al. (2007) or Vanoutrive et al. (2014) our results point again to the need for mixed land-use development and multi-purpose activity centres well connected with public transport. Such a planning strategy should reduce the public transport "missing link" issue (Vande Walle et al., 2006) that justifies the use of a car for commuting and facilitates the activities performed during working tours. Providing multiple opportunities around the work place to lower car use for commuting is not only a recommendation for urban planning but also for large employers who would like to engage in reducing the car usage generated by their employees. Facilitating access to various services (shops, leisure, family-related services) in the direct neighbourhood or within worksites will reduce travel distance to non-work activities and the use of car for commuting without forcing a decrease in the number and complexity of the activity chains.

In our particular case, we also found that sometimes two working activities are made in a row, suggesting business trips within work tours, therefore commanding the use of a private car for commuting and the business trip. Benefits would be obtained if employers with multiple site locations consolidated their infrastructure on one single site. It is unrealistic though to expect that many large employers can actually force the concentration of other businesses around them (despite some agglomeration economies). In this context, car-sharing schemes at the workplace appear to be an interesting mobility management measure to reduce car commuting and not only for facilitating business trips. In fact, all mobility measures, such as parking fees at the workplace, need to address the complexity and flexibility that seem to be required by car commuters. In addition, they definitely need to account for the socio-demographic characteristics of workers in order to be effective and fair. Further research, including multi-activity surveys before and after transport policy measures, is needed to investigate the efficiency of the instruments implemented by large employers to reduce car commuting. It is particularly important to address sustainable commuting and fine-tuning existing transport policy instruments at the work place without impeding the possibility and satisfaction of conducting daily activities.

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## 6.7 Appendix

### Sample description

| | | | |
|---|---|---|---|
| **Socio-demographic information** | | | |
| Surveyed population | 51 | Adminitrative or technical staff | 25,5% |
| Male | 25,5% | Average age | 35 |
| PhD students | 29,4% | Presence of kids younger than 12 in the household | 33,3% |
| Professors or researchers | 45,1% | Cross-borders workers | 31,3% |
| **General statistics on the Multi-Day data set** | | | |
| Total days | 705 | Weekday with working activity (Study Day) | 444 |
| Average day per individuals | 13,8 | Average "Study Day" per individuals | 8.7 |
| Total Activities | 2793 | Considered activities | 1850 |
| Home | 1046 | Home | 605 |
| Work | 565 | Work | 556 |

| **Mobility behaviour (for Study Days)** | | | | |
|---|---|---|---|---|
| | Minimum | Maximum | Average | Standard Deviation |
| Travelled distance by car (km) | 0,0 | 779,5 | 49,7 | 79,7 |
| Travelled distance by Public Transport (km) | 0,0 | 724,4 | 22,3 | 68,0 |
| Travelled distance by Soft Modes (km) | 0,0 | 64,9 | 1,6 | 4,5 |

| **Activity information (for Study Days)** | | | | |
|---|---|---|---|---|
| | Minimum | Maximum | Average | Standard Deviation |
| Activities during a work day | 2 | 11 | 4,2 | 1,7 |
| Activity time during a work day (min) | 65 | 1537 | 601 | 154 |
| Work activity time during a work day (min) | 30 | 810 | 469 | 118 |
| Non-work activity time during a work day (min) | 0 | 1207 | 131 | 144 |

## Descriptive analysis of the PLS-SEM indicators

| | ALL | | | | WorkTour | | | |
|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Mean | SD | Min. | Max. | Mean | SD |
| Age | 25 | 54 | 34.78 | 6.87 | 25 | 54 | 34.78 | 6.87 |
| Child | 0 | 1 | 0.29 | 0.46 | 0 | 1 | 0.29 | 0.46 |
| Gender | 0 | 1 | 0.266 | 0.44 | 0 | 1 | 0.266 | 0.44 |
| CarTrips | 0 | 9 | 2.40 | 1.98 | 0 | 9 | 2.13 | 1.84 |
| DistCar | 0 | 509.4 | 51.486 | 70.778 | 0 | 509.4 | 49.175 | 70.616 |
| TotDiffModes | 1 | 5 | 2.158 | 1.06 | 1 | 4 | 1.71 | 0.83 |
| LateActi | 0 | 5 | 0.89 | 0.99 | 0 | 4 | 0.115 | 0.417 |
| NWorkActTi | 0 | 1207 | 131.45 | 144.27 | 0 | 1207 | 72.08 | 113.03 |
| NWorkActi | 1 | 8 | 2.91 | 1.58 | 1 | 8 | 2.16 | 1.24 |
| TotActivity | 2 | 11 | 4.17 | 1.75 | 2 | 9 | 3.41 | 1.49 |

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# 8

# Workers' activity pattern modification due to workplace relocation

During working days, home and workplace are anchor locations shaping the daily mobility as well as the employee's activity pattern. While literature has already shown that workplace decentralization is often associated with higher car use for the commuting trip, little is known concerning the effect on activity-travel patterns.

Both chapters 6 and 7 dealt with workers' activity pattern as opposed to chapter 3, 4 and 5 that were focussing on the commuting trips. While chapter 6 dealt with the role of activity pattern on the commuting mode, chapter 7 proposes an analysis of the activity pattern variation after the move of UL staff members to Belval.

The objective of this chapter is to assess how workplace decentralization affects individuals' daily activity space. While chapter 6 was relying on travel diary data collected before the workplace decentralization and an additional similar data collection phase was needed to perform a comparison (before vs. after the relocation).

One year after the first travel diary data collection phase and 10 to 11 months after the relocation of their workplace, the same 51 respondents were asked again to participate to a new data collection phase. In order to keep an acceptable participation rate, the financial incentive has been doubled compared to the ex-ante situation. In the end, 43 respondents (84% of phase 1) provided 2 weeks of information a second time. The respondents also filled in a basic life event questionnaire; the relocation of the workplace is in fact an important exogenous event, but other important event might also have happened in respondents' life. While the majority of the respondents (27 out of 43) did not report any other significant changes in their life, the remaining faced relatively important life events. Eight persons had changed their house location for various reasons not necessary related to the university relocation. Two persons increased the car ownership of their household, while two others respondents did the opposite. Other elements such as a modification of the marital status, birth of a child, working duration modification (full time vs. part time). A modification of the children's' school were mentioned as well as long-lasting and/or permanent illness. This highlights, when studying workplace relocation or any other life event, the importance of the time interval chosen when implementing before and after data collection phase.

Using descriptive statistics as well as Standard Deviational Ellipses combined with a cluster analysis, this chapter shows how the activity space is changing due to a workplace suburbanization. The SDE technique has already been used elsewhere to measure activity space (Perchoux et al., 2014; Drevon et al., 2017; Schönfelder and Axhausen, 2003). Important ellipses modifications are, for instance, related with the employees' residential choice and workplace relocation.

This chapter is based on the paper:

Sprumont F., Viti F., The effect 1 of workplace relocation on individuals' activity travel behaviour. Submitted to Journal of Transport and Land Use.

## 7.1 Introduction

Recent publications of Rau & Manton (2016) and Schoenduwe et al. (2015) have highlighted the impact of life events on travel behavior. Key life events such as house relocation, having a baby, buying a car, etc. can drastically modify the way individuals travel or perform their activities (Van Acker et al., 2010).

As discussed by Schoenduwe et al. (2015) some life events are endogenous to individuals or the household they belong to (buying a car, house relocation) while others are not (death of spouse/husband for instance). Recently, Rau & Manton (2016) have underlined the challenges related to understanding the complex interaction processes related to "mobility milestones". Indeed, being freshly graduated, buying a car and getting a first job position are three important life events but how they interact and what is their direct and indirect effect on travel behavior is still a debated issue.

Without any doubt, employees' workplace relocation can be considered as an important life event shaping travel behavior and activity pattern of individuals. However, because of the unusual occurrence of such event, the effect of workplace relocation on travel behavior is not sufficiently studied (by the mobility biography approach or not). In addition, the few scientific publications available vary a lot in terms of their spatial context and analyzed impacts. While some life events may have a limited effect on individuals' travel behavior and activity pattern, the relocation of employees' workplace is theoretically affecting everyone, although not necessarily in an equal manner.

Bell, in 1991, was among the first to scientifically analyze the effect of workplace relocation (workplace suburbanization to be precise) on the commuting time, distance and mode. While Bell's study (1991) was focusing on an Australian case study, Cervero and Landis (1992) were discussing the impact of employment decentralization in San Francisco (US) on commuting behavior. Naes & Sandberg (1996) and Hanssen (1995) discussed similar issues in Europe. As also recently highlighted by Vale (2013), there seems to be a consensus that workplace relocation leads to higher car use for the home-to-work trip. Concerning the commuting time and distance, no generalization can be reported. While Li et al. (2016), Cervero & Landis (1992) and Bell (1991) conclude that commuting time was reduced (partly related to shift to a faster mode) after the workplace relocation, other studies, such as Cervero & Wu (1998) have shown the opposite.

Despite that, the impacts of workplace relocation on commuting trip (time, distance, modal split) and the causes related to such event have been studied, so far, to the best of the authors' knowledge, no scientific contribution is assessing how it affects the entire daily activity pattern. Using a *prior* and an *ex-ante* workplace decentralization cross-sectional survey, Bell (1991) provided some indications on this issue but it is expected that the use of two travel diaries will provide more detailed information. Understanding how a workplace relocation is affecting daily activity pattern during working days is of tremendous importance to assess and/or estimate, for instance, travel demand modifications due to changes in activity location of individuals' chained activities (such as shopping) as well as better understanding the elasticity of individuals to shift modes of transport in their commuting trips.

As already mentioned, in order to perform this analysis two travel diary data collection phases have been implemented, allowing to collect two-weeks continuous data both before and after the relocation of one of the faculties of the University of Luxembourg from a campus located in the north of Luxembourg City to the new campus located about 25km south of the Grand Duchy's capital city. By exploiting this unique data set, the aim is to obtain a better understanding of the travel behavior and activity pattern modification associated with an important life event, being workplace relocation.

## 7.2 Literature review

Since the second half of the 20th century, workplace decentralization has been considered, by national or regional authorities, as a way to decrease the transport demand pressure from the city center (Li et al., 2016, Burke et al., 2011). Bell (1991) mentions that motivation for companies or public institutions to settle in a sub-urban area may also be related to the inner city high rental prices, the lack of space and a desire to be nearer to the employees' living places.

The relocation of the employees' workplace is, according to Aarhus (2000), affecting four important commuting trip features: 1) the public transport accessibility, 2) the road accessibility, 3) the parking accessibility and finally 4) the share of employees with a short distance to work. According to the debated co-location hypothesis (Gordon & Richardson, 1997) if the majority of a company workforce is living in a city suburb, a workplace suburbanization might reduce the home-to-work distance.

Concerning the commuting mode shift, Vale (2013) recently demonstrated, using data from Lisbon (Portugal), that, when faced with a workplace relocation, employees try to keep commuting time within acceptable limits and to pursue this goal they may opt for a faster mode (often, the car). However, Vale (2013) also showed that the opposite is not true, i.e. car commuters with a shorter commuting time will not likely shift to a slower mode. An increase in car use for the commuting trip has been reported in Bell (1991), Cervero & Landis (1992), Cervero and Wu (1998), Aarhus (2000) and Hansen (1995), but Vale (2013) notes that the magnitude of this modal shift has to be analyzed carefully. Indeed, Vale (2013) shows that 73% of the employees faced with workplace relocation did not modify their commuting mode indicating a strong mode choice inertia.

Several elements can explain the modal shift towards private vehicles after a workplace relocation. First, as mentioned previously, employees try to keep travel time below a certain threshold; secondly, suburban locations often offer free or cheaper parking and good road accessibility while, on the other hand, the public transport system might be less efficient (because of higher interchange probability) (Aarhus, 2000).

According to Aarhus (2000), the sustainability of a working place, which to some extent is related to its accessibility, can be assessed by analyzing how workers adapt themselves to this new working environment. However, assessing a workplace modal shift by verifying if the employees change or not their commuting mode might be a shortsighted approach. Other decisions, in the short and in the long run, may be influenced by this exogenous event. Indeed, workers often select their residence according to several criteria and among them is the home-to-work distance. Then, after workplace relocation, it is assumed that people who face the workplace relocation and those who didn't ("new comers") will not eventually live in the same area and thus will not share similar commuting behaviors. Modal shifts towards private or public transportation modes are important statistics but the modal split before and after the relocation has also to be put into perspective. When assessing accessibility variation due to a workplace relocation not only the difference in distance matters but also the difference in accessibility. If the previous workplace accessibility was poor, a slight improvement could be seen as a positive outcome but still the accessibility of the new place may not be optimal. The opposite is also true, i.e. a slight accessibility decrease from a situation that was ideal, still, remains very good.

The loss of attractiveness related to a lower accessibility level can be seen as a negative externality penalizing private companies or major public institutions that relocate their infrastructure from the inner city center onto peripheral areas. Some individuals may select a job position because they appreciate their working environment. A change of this environment could lead to a loss of this people favoring urban environment but also a difficulty to attract new workers (Bell, 1991).

When faced with a workplace relocation, individuals might adapt themselves in various ways. In 1991, Bell pointed to several short-, mid- and long-term adaptation strategies ranging from shifting toward a faster commuting mode to compensate a longer home-to-work distance to quitting the job, or relocating house. Decisions that are likely to be significantly affected are the daily activities usually chained with the home and work activities, for instance going to do daily shopping, or eating out at lunch, etc. These decisions may, in turn, be partly the reason for modal shifts. This conscious modification of the activity patterns and thus the activity space of the individual facing workplace decentralization is one example of mid-term adaptation. Bell (1991) observed, for instance, that individuals facing a workplace relocation performed, on average, less activities (including non-work activities) after the move to the new working environment (dropping from 2.2 to 2 activity per day per person).

As indicated by mobility biography studies such as Rau & Manton (2016) and Schoenduwe et al. (2015), some life events are leading to a modification of the individuals' travel behavior. Because workplace relocation will impact all employees' commuting trip, private companies or public institutions might try to benefit from this event to change travelers' habits and in particular to foster public transport and soft modes use. Bamberg (2006) showed that a temporary intervention after an important life event (residential relocation) had an important positive effect on individual's long-term travel behavior.

This paper is contributing to the research direction indicated by Bell (1991) who has, using two cross-sectional travel surveys, analyzed the impact of workplace suburbanization of a private company on the activity pattern of the workforce. While his study proposed an analysis of the modification of the activity type and timing (including non-work activities) due to the workplace suburbanization, it did not cover an important element of the activity pattern modification, its spatial dimension.

In this paper we aim to provide this complementary view. The research question addressed in our study is the following: how do workers choose the location of the activities that were chained to the previous workplace location? More specifically, did the individuals modify all their activity locations or does some activity place remain unchanged? Being able to quantify the modification of the employees' activity space due to the move of their working place is the central objective of this paper and hence represents the main contribution of our study.

## 7.3 Context and data collection

### 7.3.1 Luxembourg, the heart of a cross-border region

At the heart of Europe, with 2586 km² of area, the Grand-Duchy of Luxembourg is a small country facing big mobility challenges. Every day, in addition to the commuting trips of its 563 000 residents, the country is also welcoming 170 000 cross-border workers representing 43% of the total working force (STATEC, 2016). These cross-border workers coming from Belgium, France and Germany generate an important pressure on the transport infrastructure of the country. While 76% of the workers living in Luxembourg commute by car, the share is reaching 89% for cross-border workers (Carpentier and Gerber, 2009). The public transport use is relatively low compared to the high service quality both in terms of frequency and coverage (Klein, 2010). As mentioned by Epstein (2010), high car use may be explained partly by the dense motorway network and the positive image of car. Regarding commuting mode choice, the important difference between the resident and the cross-borders workers is mainly related to home-to-work distance. For the residents, the median commuting distance reach 12km while it reaches 40km for the cross borders commuters (Carpentier and Gerber, 2009). Despite being a car dependent country, ambitious modal split targets have been adopted. By 2020, 25% of all the trips should be travelled using non-mechanized modes of transportation (walk and bike) while within the remaining 75%, 25% should be done by PT. In brief, 25% of the trips should be done by soft modes, 19% of the trips by public transport and, finally, 56% by car. According to the private company Tom-Tom (Tom-Tom, 2015), a 30-min commuting trip will generate 87 hours of delay yearly.

The high congestion levels experienced in Luxembourg are also related to the monocentric development of the country. Out of the 380000 jobs available in the country about one out of two is located in Luxembourg-City (Walther & Dautel, 2010). In order to decrease the pressure (in terms of commuting flow, residential prices, etc.) on Luxembourg-City, and to reach a more balanced polycentric development across the country, a *decentralized concentration* land use policy has been implemented. Chilla & Schultz (2014) describe this policy as the "concentration of urban and infrastructure development in selected cities and communities of different levels of centralization". The development of Belval, a new town located in the south-west part of the country, is seen as a powerful tool to reach a more polycentric development. This place, a former industrial area, will host, from 2017, most of the university infrastructure and it is already hosting many national research centres, company headquarters, a hotel, theatres, music hall, a train station and various types of accommodations. This new activity pole is also expected to increase the attractiveness of the surrounding cities, thus in the long run favouring the expansion of the whole south-west region.

### 7.3.2 The University of Luxembourg

Founded in 2003, the University of Luxembourg is welcoming 6500 students and 1500 staff members. Until August 2015, the majority of the University activities were located on three different campuses which were in Luxembourg-City (namely Kirchberg and Limpertsberg campuses) or a few kilometers away from the city centre (Walferdange campus). In September 2015, the faculty hosted in Walferdange has been the first one to relocate, and the buildings of the old campus are not used anymore by the University.

Since its creation, the university has constantly grown in number of employees and students and has now slowed down its expansion due to the available infrastructure. To solve this issue and to foster land-use polycentric development the national government has imposed the relocation of the university in Belval. The move of most of the university facilities was guided by a lack of space due to a constant growing population (both students and staff members) and the wish to concentrate all activities on one site.

A previous study, involving an earlier travel survey data showed that most of the staff members will be negatively impacted in terms of commuting traveling, the most impacted staff members being the German workers, while only a few people will beneficiate of shortening commuting distances (Sprumont et al. 2014). In general, this workplace relocation will increase the commuting of the university staff members of, on average, 18% (from 28.7 to 33.8km). On the other hand, this workplace relocation is seen as a unique opportunity to foster a sustainable vision of mobility: carrot-stick measures are indeed being implemented to enforce modal shifts towards public transport and soft modes. A parking fee has been introduced, a university car-sharing system, an online carpooling platform as well as an inter-campus shuttle have been implemented in order to mitigate the expected car use increase for the commuting trip.

## 7.4 The data collection phases

Being able to analyze the effect of workplace relocation on the activity pattern and the travel behavior of the university employees is a challenge in terms of data collection. In 2015, prior to the workplace relocation of some members of the University of Luxembourg, a communication campaign has been implemented to attract staff members willing to participate to our study.

Respondents were providing information regarding their activities (type, location, duration) and the associated trip (travel time, travel mode) using a dedicated website. A gift voucher was used as an incentive to keep dropping rate as low as possible. Between May and June 2015, respondents had to provide 2 weeks of information. An overview of the questionnaire structure is provided in the appendixes.

One year after the first data collection phase, the same individuals were re-contacted and invited to repeat the survey. In total 8 people could not participate to the second round of data collection for different reasons. Two respondents were not available during the specific period, one respondent was in maternity leave and 5 respondents were not working anymore at the university at that time.

In total, 43 individuals took part to both the 2015 and 2016 data collection phases. In 2016, an additional questionnaire regarding the modification of other elements in their life was also submitted to the respondents before providing them the last monetary incentive (which was twice as much as the first one). This final set of questions informed us on the possible mid and long-term adaptation strategies (see Bell, 1991, p. 151, for a detailed description of the adaptation strategies). In total, 27 out of the 43 respondents did not report any significant event such as buying a car, home relocation, having a baby, etc., therefore workplace relocation was for them the main event affecting their commuting traveling experiences and their activity-travel decisions. On the other hand, among the respondents, 8 people relocated their home address.

Because the objective of this study is to assess the effect of workplace relocation on activity-travel behavior, only data encoded during weekdays where a work activity has been registered have been taken into account. Weekend days, bank holidays or week days without any work activity described were simply not considered. For the 2015 data set, out of the 598 days described by the 43 respondents, 370 (62%) are retained for analysis while for the 2016 data set, out of the 615 days of information, 361 (59%) were retained for the following analysis.

Clearly, the size of the dataset collected cannot guarantee generality of the observed changes in both short- and long-term decisions, so the results presented in this section and later in the analysis of the mobility patterns. Moreover, we cannot fully assure that all long-term decisions and travel choices of the respondents have converged towards a new set of habitual routines within the chosen time interval. However, we argue that the exploratory analysis presented in this paper provides several directions for further research, and gives clear indications of the importance of performing in the future similar types of data collection campaigns.

## 7.5 Descriptive analysis

All the respondents have one characteristic (at least) in common, i.e. between 2015 and 2016 their workplace has shifted from Walferdange to Belval. While the comparison of both 2015 and 2016 travel diaries is assumed to be the adequate tool to analyze the short-term adaptation (commuting mode change, modification of the activity pattern) some respondents have changed some elements of their life that can be considered as long-term adaptation to workplace relocation, for instance changing their residence or buying a car. In total, eight individuals (18.6%) relocated their house but not necessarily because of the workplace relocation, and not always long-term decisions move in the direction of improving the commuting traveling experience, and not necessarily the individuals aim to minimize the commuting times. In general, respondents may try to trade off this cost with other benefits that could be obtained with other long-term decisions. Two respondents moved from Luxembourg to Trier (Germany) because of cheaper rental prices across the border. Another respondent, was, before the relocation, living near Belval, but after the relocation this person decided to move because he/she didn't want to live and work in the same place. Such kind of behavioral adaptation is in line with the theory of Redmond and Mokhtarian (2001) stating that travelling might, to some extent, have a positive utility. The behavior of this individual can be synthetized by: the working place should be close, but not too close to home.

On average, the respondents have a median number of activities per day of 4.1 in 2015 and 4.2 in 2016. Important differences can be observed between individuals, for example, one individual performed 2.5 activities per working day which is very close to a daily Home-Work-Home and another one performed on average 7 activities per working day.

*Impact on the commuting distance*

In 2015, before the workplace relocation, the average home-to-work distance for the 43 respondents reached 30.2 km and 14 had a commuting trip shorter than 10km. Of course, the commuting distance was different for Luxembourgish residents than for cross-border workers. Indeed, in 2015, the cross border workers had on average on commuting trip of 60.4 km and, on the other hand, Luxembourgish residents had an average commuting distance of 15.5km.

In 2016, after the move of Walferdange campus to Belval, the average commuting distance reached 38.5km. Only 5 survey respondents have now a home-to-work trip of less than 10km. From the 14 staff members who had, in 2015, a short commuting, 12 (the 2 remaining have relocated their house) have now a commuting trip longer than 20km. The cross-border workers have in 2016, on average, a commuting distance of 67km while for residents their trip on average reaches 21km.

Concerning the commuting distance, even if the sample is not big enough to make a solid generalization of the observations, the home-to-work trips have, on average, significantly and systematically increased in length. Intuitively, this increase of the commuting distance is related to staff members' previous residential choices. While, before the relocation, many respondents were living relatively close to their work place, the move of the university infrastructure had a big impact for them. In addition, the staff members living in the surrounding of the new campus are too few to compensate the general distance increase.

*Impact on the commuting mode choice*

As a confirmation of what Vale (2013) indicated on travel mode choice inertia, 80% of the respondents did not change their main travel mode despite the workplace relocation. In 2015, 56% of the sample was commuting by car, 42% by public transport and 2% by soft modes. After the relocation, 60% of the individuals are doing their home-to-work trip by car, 35% using public transport and 5% by walk or bike.

Compared to Bell (1991), where the modal shift towards car was important, the respondents did not change significantly their habits. This relatively small modal split variation after the workplace relocation, despite a general distance increase, is probably related to the parking costs imposed on the Belval site. As pointed out by Aarhus (2000) the availability of free parking is a strong car use determinant for the home-to-work trip. While the University of Luxembourg was providing free parking on the old campus site (Walferdange) this is not anymore the case on the new campus location (Belval).

*Impact on the commuting time*

While the commuting distance has increased in a rather important way, the commuting time of the respondents shifted from 47 minutes to 52 minutes. This increase of 5 minutes is rather small if compared to a distance increase of 8 km.

The second data collection phase was organized 11 months after the workplace relocation; thus, our assumption is that respondents would have implemented the short-term adaptations (commuting mode choice, activity location). However, it is not possible to know if all the respondents have finished their exploration phase regarding for instance commuting mode choice, route choice or activity location. On the other hand, other respondents already adopted mid- and long-term strategies to cope with the relocation of their workplace to Belval. A third data collection phase would permit to know more about the length of the exploration phase.

| | 2015 | | | | 2016 | | | |
|---|---|---|---|---|---|---|---|---|
| | Min | Max | Average | STDEV | Min | Max | Average | STDEV |
| Commuting time (in minute) | 11,9 | 118,0 | 47,3 | 23,3 | 10,0 | 122,1 | 52,4 | 27,7 |
| Commuting distance (in km) (on road the network) | 2,7 | 118,0 | 30,2 | 27,2 | 0,7 | 110,7 | 38,5 | 27,6 |
| Activity per considered day per respondent | 2,5 | 7,0 | 4,2 | 1,1 | 2,4 | 9,4 | 4,3 | 1,4 |
| Kilometres travelled per considered day per respondent | 13,9 | 249,9 | 83,6 | 56,2 | 8,8 | 223,7 | 91,9 | 52,4 |
| Commuting modal split | Car: 56%, PT: 42%, Soft: 2% | | | | Car: 60%, PT: 35%, Soft: 5% | | | |

Table 22 Comparative table between 2015 and 2016 situations

## 7.6 Methodology

With the objective of finding a synthetic measure of the effect of workplace relocation on the activity patterns of the university staff members, we adopt in this study the Standard Deviational Ellipses approach. Our goal is to show that such an event produces a systematic change in the spatial distribution of activities.

The quantification of spatial event dispersions using Standard Deviational Ellipses (SDE) is a well-established technique dating from the beginning of the 20th century (Lefever, 1926). Since then, SDE technique has evolved (Yuill, 1971) gained in robustness (see for instance Gong, 2002, who discusses whether a standard deviation curve should be used instead of the classical SDE) and popularity (Buliung & Kanaroglou, 2006). The characterization of the individuals' activity spaces using Standard Deviational Ellipses (SDE) has already been successfully implemented in activity-travel behavior analysis (Schönfelder & Axhausen, 2003; Drevon et al., 2013; Perchoux et al., 2014).

Our dataset is characterized by a relatively low number of individuals (43 in total) but also by a relatively large number of days/activities described per respondents. SDE is seen as an interesting tool to assess a modification of the activity space of the individuals after their workplace relocation. Of course, other methods such as the space-time prism (Kwan, 1998) or the convex hull surface (Perchoux et al., 2014) might also provide valuable information on the activity space or the activity pattern. However, Standard Deviational Ellipse, in addition its efficiency in characterizing the activity space, seem to be the most appropriate approach to compare two different activity spaces and derive a set of indicators such as length, rotation or area variation, etc.

The 86 ellipses (1 per respondent for all reported working days before and after the relocation) have been obtained using ArcGIS software and a dedicated tool to perform SDE.

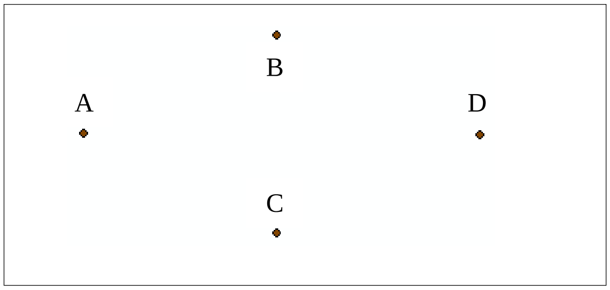
The two main parameters (length, width) of the Standard Deviational Ellipse are defined as:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n}}$$

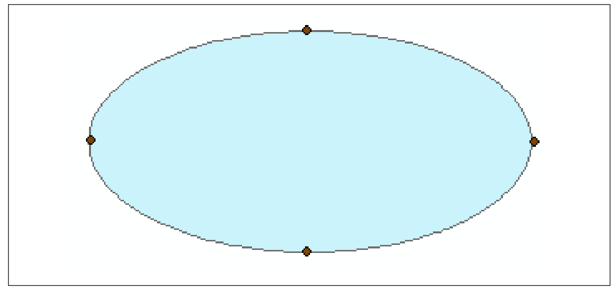
$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{Y})^2}{n}}$$

Where $x_i$ and $y_i$ are the coordinates of location I and where $\bar{X}$ and $\bar{Y}$ are the mean centre for all the activity locations and n equals the total number of activity considered for the ellipse generation (Yuill, 1971). More information on the weighting procedure and on the angle of rotation computation can be found in Mitchell (2005).

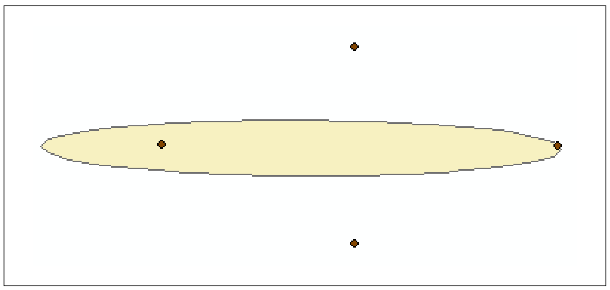
Figure 17 provides an illustrative example of how SDE works using different weighting parameters. The west location A is the individual's home and is, in this example, visited for 5 days and for a total of 76 hours. The east location D is the individual's workplace and is visited also 5 times, but for less time, i.e. a total of 40 hours. The north and south locations (B and C, respectively) are both leisure activities, the former being a restaurant visited once for a total of 1 hour and the latter is a sport infrastructure that has been visited 4 times (for a total of 4 hours). Sub-picture 1b, shows a simple non-weighted SDE while the sub-picture 1c and 1d show respectively time (activity time) and visits weighted SDE



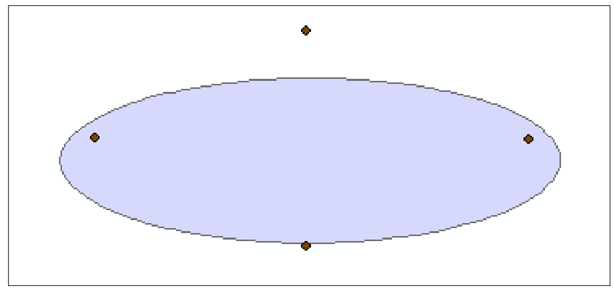

a) Four activity locations



b) Four activity locations with non-weighted SDE



c) Four activity locations with time weighted SDE



d) Four activity locations with visits weighted SDE

| | |
|---|---|
| Location A: Living place: 5 visits – 4560 minutes | Location D: Workplace: 5 visits – 2400 minutes |
| Location C: Sport Club: 4 visits – 240 minutes | Location B: Restaurant: 1 visit – 60 minutes |

Figure 17 Standard Deviational Ellipses with different weights

We argue that a non-weighted SDE would not be not appropriate for our study, because all the visited places would appear to bear the same importance level, even if they have been visited once for 5 minutes or 10 times for a total of 80 hours. The time-weighted approach is giving importance to places that are visited for long durations, hence provides an unbalanced result between short activity (lunch in a restaurant for instance) and long duration activities (12h stayed at home before going to work again). Thus, the frequency-weighted SDE has been selected due to the fact that the weight difference between anchor locations and locations visited occasionally for a limited period of time is existing but remains reasonable.

## 7.7 Results of the SDE

ecause activity places that are located far away from the mean center have an important effect on the SDE feature (rotation, length and width), some remote and non-habitual activity locations were not considered as it was assumed that they were exceptional events not recurring every week. The specificity of the sample population (mostly academic personnel) is partly responsible for special events to be observed such as conferences abroad (Zurich, London, Paris). Some individuals were also starting travelling to visit family members or friends in remote places on Friday evening. Out of a total of 581 different activity locations, 23 places were not retained for the construction of the 86 Standard Deviational Ellipses.

Due to the important distance (20km) between the old and the new workplace, it was foreseen that the relocation would have a non-negligible impact on the activity space, represented by the Standard

Deviational Ellipses. Concerning the Ellipses' area variation between 2015 and 2016, for instance, the median increase reached 56%. In total, 25 respondents (out of 43) have experienced an increase of their activity space. Concerning the length of the SDE, the median increased is 50%. Of course, this increase of the ellipses' length is associated with the commuting distance increase mentioned previously which is concomitantly affecting the ellipses' area.

The area of the activity space is varying significantly depending on the individuals' characteristics. For instance, in 2015, one respondent performed 38 activities during 10 working days within an activity space of 6 $km^2$. At the other side of the spectrum, one respondent had, in 2015, an activity space of 2729 $km^2$.

*Clustering analysis*

The ellipses have been generated on the individual's activity locations both for 2015 (before the relocation) and 2016 (after the relocation). In order to verify if some individuals had an activity pattern variation which could be considered as abnormal compared to the total sampling, a basic multivariate outlier analysis has been performed. The Mahalanobis distance computed for each individual leads us to exclude one individual out of the clustering analysis (appendix B includes the The Mahalanobis and the $Chi^2$ test). After verification, the length of the activity space (represented by the SDE) of this person increased of 1400% and its area increased of 4700%. In this case, a professional collaboration with an institution from a neighbouring country is the cause of such important variation in the activity space.

Then, a K-mean clustering approach was performed on a derived dataset consisting on the variation of the ellipses between 2015 and 2016. More specifically, the six variables considered for the cluster analysis are: 1) ellipses width change 2) ellipses rotation change 3) ellipses length change 4) ellipses area change 5) overlapping between 2015 and 2016 ellipses 6) variation of the distance between respondents home and the center of the ellipse after the workplace relocation.

The results of the K-mean clustering approach with three clusters are presented in Table 23. Cluster 1 is gathering individuals who had the smallest overlapping (17%) between their 2015 and 2016 activity spaces. Respondents belonging to this cluster also faced an important rotation of their activity spaces (106 degrees on average). Obviously, members of cluster 1 faced an important modification of their activity space after the relocation. It turns out that from the five people of this cluster, 3 decided to relocate their residence. Interestingly, these three individuals were also living in Luxembourg before the relocation meaning that their residence relocation was done within the national borders. All the members of this group are living in Luxembourg.

| **Cluster** | **1** | **2** | **3** |
|---|---|---|---|
| Size | 5 (12%) | 11 (26%) | 26 (62%) |
| Average width change (in %) | 13,3% | 79,2% | 18,9% |
| Average rotation change (in degrees) | 105,67 | 48,70 | 12,65 |
| Average length change (in %) | 67,0% | 79,6% | 42,7% |
| Average area change (in %) | 139,3% | 199,8% | 57,9% |
| Average overlapping (in%) | 13,9% | 34,4% | 32,7% |
| Average variation of the Home - Ellipse centre distance (in%) | 17,0% | 80,5% | 46,2% |

Table 23 Results of K-Mean cluster analysis

Cluster 2 is composed of individuals who faced an important increase of their activity space after the workplace relocation. Indeed, on average, the width of their SDE increases of 79%, the length increases of 80% and consequently the area increase reaches 200%. In 2015, 10 out these 11 respondents were also living in Luxembourg. As introduced previously, an important increase of the activity space may be due to the fact that these people are still in exploration phase or trying to combine the activity location they know (because of habits, emotional relation, etc.) and perform activities around their new workplace. Such behaviour could lead individuals to have a bigger activity space.

The last cluster gathers respondents that faced the smallest rotation, length and area variations. Half of the respondents within this cluster are university staff members living outside Luxembourg. Out the 13 cross-border workers (in 2015), 12 (92.3%) are in this cluster. Because of a small rotation and a rather important overlap (32.7%) between 2015 and 2016 activity spaces, respondents from this cluster probably had to produce less in effort to cope with the workplace relocation, at least concerning their activity-travel behaviour.

| | Cluster1 | | Cluster 2 | | Cluster 3 | | Total |
|---|---|---|---|---|---|---|---|
| | # | % in the cluster | # | % in the cluster | # | % in the cluster | |
| Cross-border | 0 | 0% | 1 | 9% | 13 | 50% | 14 |
| Female | 4 | 80% | 10 | 91% | 17 | 65% | 31 |
| Male | 1 | 20% | 1 | 9% | 9 | 35% | 11 |
| PhD students | 2 | 40% | 5 | 45% | 6 | 23% | 13 |
| Prof, PostDoc and Researchers | 3 | 60% | 4 | 36% | 11 | 42% | 18 |
| Admin or technical positions | 0 | 0% | 2 | 18% | 9 | 35% | 11 |
| Living with children | 1 | 20% | 3 | 27% | 8 | 31% | 12 |
| Average Age | 34,4 years | | 34,4 years | | 35,3 years | | 34,9 years |

Table 24 Socio-demographic characteristic among clusters

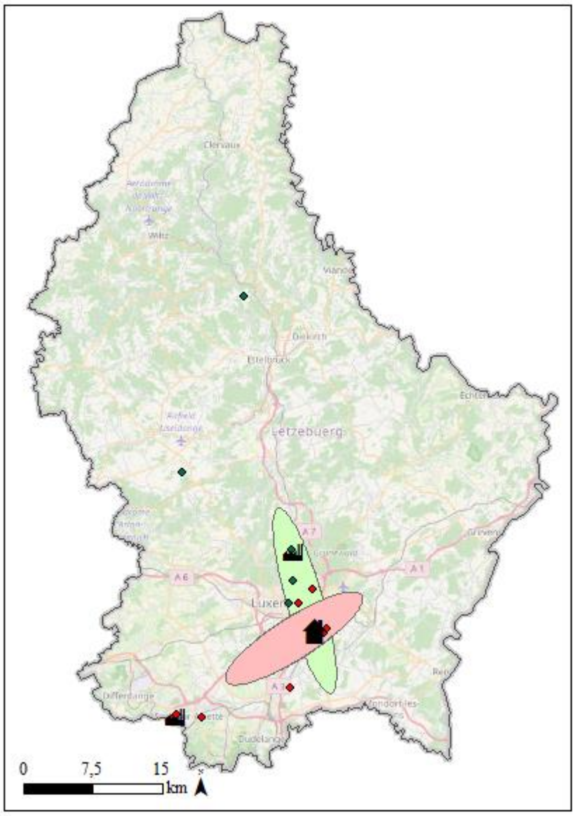
Table 24 presents the socio demographic characteristics among the 3 different clusters. For instance, as discussed, the repartition of cross-border workers among the clusters is uneven. Considering the low number of respondents, these results are provided as an indication and cannot be proven general.

Figure 18 provides a visualization of clusters representativeness. These clusters representatives have been selected because they have the shortest distance to the centre of the cluster. Appendix B contains details to analyze individually the variation between the 2015 and 2016 SDEs, the cluster allocation and the distance to the center of the cluster.

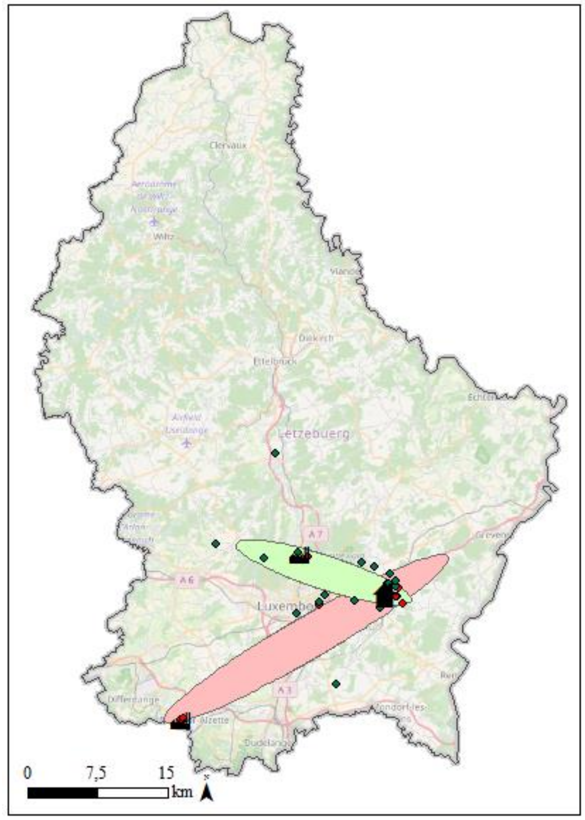
The workplace relocation is having different impact on the activity space represented by the SDE. The effect depends widely on the position of the individual’s home compared to the old and the new workplace locations. An interesting element is that, after the workplace relocation, very few responds still had activities within a buffer of 5km around the previous campus. Only four respondents, representing less than 10% of the sample population, had in 2016 activities in the direct vicinity of their former working place. This indicates that, after a year, people have adapted their daily activity pattern, keeping the activity place close to their home and replacing activity location of the activities close to the previous work place.

A simple correlation analysis between the 2016 ellipses length and the 2016 commuting distance revealed a correlation of 89%. Intuitively, this indicates that the commuting distance is strongly affecting the length of the activity space.

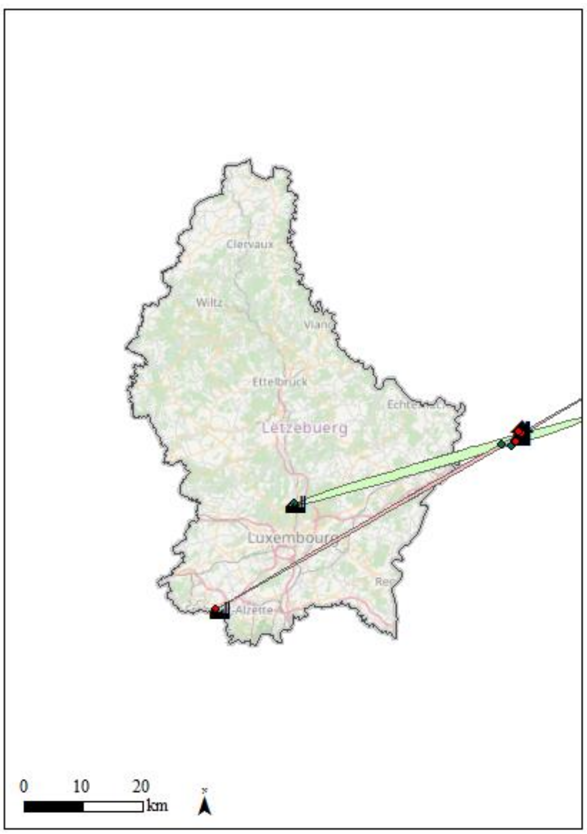
The average modification of the commuting distance (on the road network) has been extracted for each of the three clusters. While it has already been mentioned that respondents from cluster 1 faced huge change in their activity space, they also faced an increase of 126% of their Home-to-Work distance (from 10km to 22.6km). The second cluster composed mainly of people living in Luxembourg and who faced an enlargement of their activity space had to cope with an increase of 76% of their commuting distance (from 15.3km to 26.9km). Rather logically, respondents from cluster 3 of whom 50% were cross border workers had in 2015 a very long commuting trip (41.3km) only faced a minor increase of 13% and now commute, on average, 46.8km, for a one way trip.




a) Representative of cluster 1




b) Representative of cluster 2




c) Representative of cluster 3

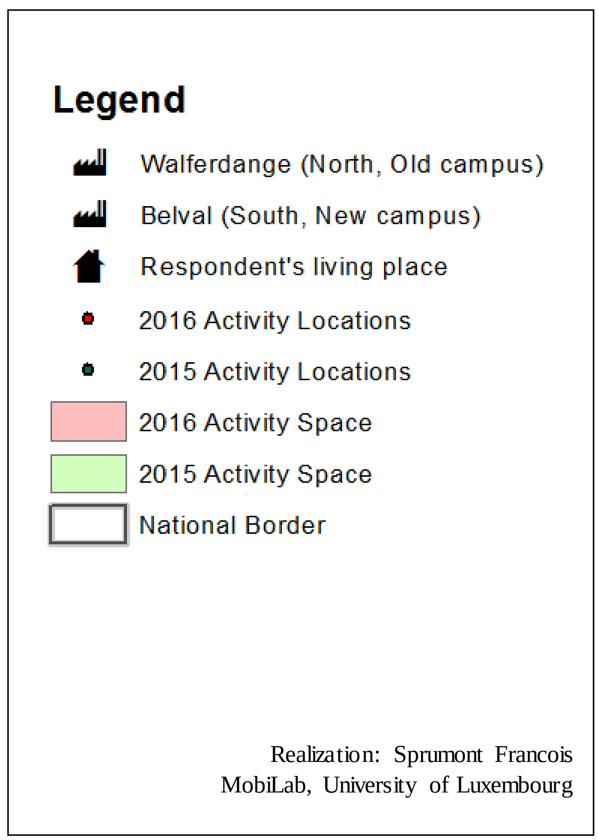



Figure 18 Clusters Representative

## 7.8 Conclusion and discussion

Similarly to findings available in the past scientific literature, and despite using a small sample, it has been confirmed that a workplace decentralization leads to a longer home-to-work commuting trip. This result is in conflict with the co-location hypothesis (Gordon & Richardson, 1997).

Due to the important distance between the new and the old workplace (20km), the activity spaces of the respondents have been importantly modified. The employment of Standard Deviational Ellipses combined with a cluster analysis allowed a quantification of the modification of the activity space and the distinction between three types of profile.

After the workplace relocation, very few individuals have performed activities in the area of the old campus. Of course, such impact might have some important negative impacts on the visiting frequency of services located close to the previous working space. The transport demand might also change depending on the size of the institution relocating.

The analysis developed in this paper showed that, during working days, the place of residence and the working place were important anchor points shaping the entire activity space. The analysis performed can be reproduced for different case studies, and, to some extent, employed in order to forecast the effect of another workplace relocation on the employees' activity space.

For the land-use management side, the development of Belval which is line with the so-called *decentralized concentration* concept turns out to be an effective way to decrease the pressure on the transport infrastructures of the capital. Indeed, only 4 individuals still have activities in the area of the old campus. While no quantitative analysis has been done specifically on this topic, it's assumed that the effectiveness of such policy strongly depends on the distance between the new and the old workplace. While in this case, with a 20km distance, the vast majority of the individuals have totally changed their activity space, a relocation of 5km would have most likely led people to keep some activity locations identical, by habit. If the workplace decentralization's main objective is to reduce the transport demand around the old working place, the distance to the new working place is an important element not to be ignored.

Analyzing the effect of a workplace on employees' travel behavior and activity patterns is a complex task, where the research objective has to be thoroughly designed. For instance, concerning the data collection, if the objective is to assess the accessibility or sustainability of the new working place, it's suggested to analyze the commuting behavior of the "new comers" only. If the goal is to check the long term adaptation (moving to a new home, buying a car) to a workplace relocation then it is suggested to do the second data collection a couple of years after the move. Finally, if the goal is to understand the short-term adaptation (mode change, activity location modification) to the workplace relocation, such as in this study, collecting data before and up to one year after the relocation is the recommended strategy.

This scientific study can be considered explorative, and future developments would be needed to allow a generalization of the results. Bigger and more frequent data collection should be organized. Due to the difficulty to collect data regarding effect of workplace relocation on activity-travel behavior, this issue remain widely unknown. Notwithstanding, firm relocations is a frequently observed event and the effect on employees has to be further investigated. The use of ICT and other transformative technologies should also be studied in this context because these technologies might mitigate the potential negative impact of workplace relocation on individuals time budget.

## Acknowledgements

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## Appendix A: the multi-day survey

The below questions constitute a textual overview of the information asked to the respondents via the web-based survey for 2 weeks both before and after the workplace relocation.

1. Could please provide us your name and surname ? (this will help us to distinguish your daily activities from the ones of your colleagues)
2. On which days happened the activity you want to describe ?
3. **Trip 1** - At what time did you start travelling to reach the first activity location ?
4. **Trip 1** - How long did it take to reach this first activity ? (format example: 2h30)
5. **Trip 1** - How did you go to this first activity ? (If you have one single mode, fill in first column only)
6. **Activity 1** - Could you, please, describe the purpose of the first trip ?
7. **Activity 1** - Can you tell us the destination of your first activity (name of the place, name of the village) ?

You have provided information for one activity, you can now 1) close your internet browser or 2) describe another activity

8. **Trip 2** - At what time did you start travelling to reach the activity location ?
9. **Trip 2** - How long did it take to reach this activity ? (format example: 2h30)
10. **Trip 2** - How did you go to this activity ? If you have one single mode, fill in first column only
11. **Activity 2** - Could you, please, describe the purpose of the trip ?
    (If Home is selected different questions appear)
12. Do you have another activity to encode TODAY
    -Yes
    - No, I am at home until tomorrow morning
    - I am not at home but I have no other activity to encode
    (if answer "No, I am at home until tomorrow morning", a closing message appear")

You don't have any more activity to register for TODAY. You can click on the original internet link to describe activities of another day

## Appendix B: Variables used for the cluster analysis, Mahalanobis distance and cluster classification

| ID | Width | Length | Area | Rotation | Overlap | Ho. Centre variation | Mddist | Chi2 | Cluster | Dist to the cluster's center |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -0,58 | 0,15 | -0,52 | 28,18 | 0,16 | 0,43 | 1,30 | 0,9715 | 3 | 15,59 |
| 2 | -0,84 | 0,56 | -0,75 | 21,15 | 0,13 | 0,68 | 1,46 | 0,9624 | 3 | 8,67 |
| 3 | -0,91 | 1,53 | -0,78 | 9,81 | 0,06 | 3,49 | 9,71 | 0,1373 | 3 | 4,64 |
| 4 | -0,70 | 0,53 | -0,54 | 14,42 | 0,00 | 1,30 | 2,96 | 0,8142 | 3 | 2,45 |
| 5 | 0,14 | -0,16 | -0,05 | 106,33 | 0,26 | -0,35 | 7,18 | 0,3043 | 1 | 1,87 |
| 6 | -0,74 | -0,59 | -0,89 | 2,00 | 0,11 | -0,85 | 5,07 | 0,5351 | 3 | 10,92 |
| 7 | 0,72 | 1,71 | 3,67 | 20,58 | 0,65 | 0,76 | 2,39 | 0,8803 | 3 | 8,64 |
| 8 | -0,05 | 1,07 | 0,96 | 50,45 | 0,35 | 0,36 | 1,11 | 0,9811 | 2 | 2,27 |
| 11 | 0,52 | -0,70 | -0,54 | 6,01 | 0,29 | -0,93 | 2,68 | 0,8473 | 3 | 6,98 |
| 12 | 1,97 | 0,06 | 2,16 | 13,68 | 0,42 | 0,18 | 3,89 | 0,6915 | 3 | 2,64 |
| 13 | 0,25 | 0,79 | 1,22 | 48,03 | 0,22 | 0,35 | 0,47 | 0,9981 | 2 | 1,25 |
| 15 | 0,33 | -0,93 | -0,91 | 61,84 | 0,00 | -0,87 | 4,14 | 0,6576 | 2 | 13,68 |
| 16 | -0,78 | 0,53 | -0,66 | 12,40 | 0,20 | 0,34 | 1,49 | 0,9601 | 3 | 1,61 |
| 17 | 2,19 | 14,17 | 47,33 | 117,42 | 1,00 | 2,32 | 39,94 | 0,0000 | NA | NA |
| 19 | 0,99 | 1,30 | 3,58 | 125,69 | 0,41 | 0,33 | 8,86 | 0,1815 | 1 | 20,17 |
| 20 | 0,41 | -0,11 | 0,26 | 3,66 | 0,55 | -0,41 | 2,95 | 0,8146 | 3 | 9,06 |
| 21 | -0,54 | 1,42 | 0,11 | 111,82 | 0,00 | 0,48 | 9,10 | 0,1682 | 1 | 6,37 |
| 23 | 1,76 | -0,27 | 1,02 | 24,16 | 0,19 | 0,04 | 5,35 | 0,4997 | 3 | 11,65 |
| 24 | -0,49 | 2,13 | 0,61 | 40,53 | 0,11 | 1,62 | 6,46 | 0,3739 | 2 | 8,53 |
| 25 | 0,51 | 1,10 | 2,16 | 0,69 | 0,88 | 1,33 | 8,36 | 0,2131 | 3 | 12,13 |
| 26 | 3,23 | 1,65 | 10,20 | 38,25 | 0,48 | 2,59 | 12,29 | 0,0558 | 2 | 13,65 |
| 27 | 1,00 | 1,66 | 4,31 | 89,85 | 0,03 | 1,29 | 6,75 | 0,3442 | 1 | 16,18 |
| 28 | 1,96 | 0,58 | 3,68 | 11,80 | 0,57 | 1,07 | 3,12 | 0,7931 | 3 | 3,73 |
| 29 | 0,59 | 1,60 | 3,14 | 45,72 | 0,30 | 0,83 | 1,16 | 0,9789 | 2 | 3,29 |
| 30 | 1,00 | 0,51 | 2,02 | 20,95 | 0,77 | 0,03 | 4,31 | 0,6343 | 3 | 8,49 |
| 31 | -0,35 | 2,76 | 1,46 | 16,36 | 0,48 | -0,45 | 16,56 | 0,0110 | 3 | 4,60 |
| 32 | 0,31 | -0,58 | -0,45 | 1,97 | 0,03 | -0,72 | 4,71 | 0,5819 | 3 | 10,85 |
| 33 | -0,69 | -0,13 | -0,73 | 48,32 | 0,04 | -0,41 | 2,50 | 0,8683 | 2 | 3,49 |
| 36 | -0,22 | 2,39 | 1,64 | 38,26 | 0,47 | 2,80 | 6,93 | 0,3276 | 2 | 10,80 |
| 37 | -0,56 | 0,04 | -0,54 | 19,85 | 0,01 | 0,23 | 2,19 | 0,9010 | 3 | 7,35 |
| 38 | 1,13 | 0,48 | 2,16 | 67,93 | 0,69 | 2,25 | 10,18 | 0,1174 | 2 | 19,29 |
| 39 | 1,32 | -0,33 | 0,56 | 20,74 | 0,47 | -0,54 | 2,23 | 0,8972 | 3 | 8,27 |
| 40 | -0,62 | 0,53 | -0,42 | 13,39 | 0,05 | 0,47 | 1,94 | 0,9254 | 3 | 1,52 |
| 41 | -0,50 | -0,32 | -0,66 | 4,80 | 0,14 | -0,34 | 2,89 | 0,8225 | 3 | 8,06 |
| 42 | -0,92 | -0,88 | -0,99 | 94,66 | 0,00 | -0,89 | 11,63 | 0,0707 | 1 | 11,46 |
| 43 | -0,80 | 0,50 | -0,70 | 12,04 | 0,06 | 0,61 | 2,04 | 0,9156 | 3 | 1,75 |
| 44 | 2,30 | -0,17 | 1,74 | 39,21 | 0,38 | 0,00 | 5,36 | 0,4987 | 2 | 9,69 |
| 45 | 0,97 | 1,06 | 3,05 | 14,07 | 0,39 | 4,06 | 12,17 | 0,0582 | 3 | 4,70 |
| 46 | 0,18 | 0,31 | 0,55 | 10,62 | 0,54 | 0,59 | 2,26 | 0,8942 | 3 | 2,05 |
| 47 | -0,55 | 0,27 | -0,43 | 1,63 | 0,47 | -0,49 | 4,00 | 0,6769 | 3 | 11,14 |
| 48 | -0,55 | 1,01 | -0,09 | 8,76 | 0,37 | 1,00 | 1,93 | 0,9260 | 3 | 4,09 |
| 50 | 2,32 | -0,11 | 1,94 | 57,13 | 0,74 | -0,66 | 7,32 | 0,2921 | 2 | 8,75 |
| 51 | 1,75 | 0,25 | 2,45 | 15,20 | 0,51 | 0,11 | 2,64 | 0,8528 | 3 | 3,55 |

# 8

# Conclusion and Policy recommendations

## 8.1 Conclusions and Policy Recommendations

The main objective of this PhD thesis was to understand the impact of a workplace relocation on the activity-travel behaviour of concerned employees. The main motivation for undertaking this research has been the opportunity offered by experiencing directly, and partly influencing, the relocation of the University of Luxembourg old campus(es) to the new Campus of Belval, located around 25km south of Luxembourg City, where the other campuses of the university were located. A series of initiatives supported by the Cell for Sustainable Development at the UL Rectorate, was initiated in 2011, among them a sustainable transport policy vision consisting of an information campaign centered around regular (bi-annual) travel surveys, and a set of transport services implemented to cope with the transition phase where many activities had to be done on different campuses, and the absence of dedicated transport services to connect the campuses.

To address this task properly, analysis on the activity pattern and the commuting behaviour have been tackled in rather independent chapters.

The motivation for **chapter 2** was to understand if the workplace relocation faced by the University of Luxembourg as well as the development of Belval, a decentralized academic centre, was a unique case study or not. Gather information on travel behaviour variation due to institutions, both public or private, relocation was necessary to understand all the specificities of the Belval case study. This resulted in a unique literature review focusing on the effect of workplace relocation on the different travel behavior determinants and alternatives.

Using the 2012 staff travel survey data, which was collected 2 years before the move of some facilities of the University of Luxembourg, **chapter 3** proposed a mode choice forecasting analysis using well known Discrete Choice Theory models. Although the forecasting provided expectations of sensible mode changes and suggested different policy recommendations, the analysis of the 2016 survey data, i.e. 4 years after the first data collection campaign, revealed that predictions were erroneous. This was not only due to modelling assumptions and simplifications, but also was caused by a significant change in the expected existing services and mobility factors (e.g. the adoption of parking management, the deployment of inter-campus shuttle services, a car-sharing service, etc.).

A main aspect studied in this thesis, related to travel behavior, is the concept of commuting satisfaction, which has been investigated in **chapter 4** in relation with mode choice determinants. Indeed, commuting satisfaction was seen as an indicator for potential short and/or long-term coping strategies in order to reach a certain travelling satisfaction threshold. The proven correlation between stated commuting satisfaction and the (Logsum) utility concept, which on the other hand can be estimated through measurable information (travel times, monetary costs, etc.), provides an important basis for assessing transport policy and mobility management strategies aimed at fostering sustainable mobility.

Although commuting satisfaction and utility are sensibly correlated, other welfare aspects can reduce this correlation. An example found in the data analysed in chapter 4 was the relation revealed by cross-border commuters, which seem to adopt a significant trade-off between travelling satisfaction and residential choice satisfaction, or, in other words, residential factors, which were not included in the utility for a commuting trip, seem to play an important role. Following this reasoning, **chapter 5** provided an assessment of, residential-related attributes on commuting satisfaction. The 2012 data included few questions regarding residential choices of the respondents. Interestingly, the effect of long term decisions as well very short-term decisions, such as doing grocery shopping during lunch time on the commuting trip, have been investigated.

**Chapter 6** focused on the effect of the activity pattern complexity on the commuting mode or more specifically on working tours. Discussion on possible ways to mitigate the effect of complex activity pattern on car use for the home-to-work trip had been investigated. Using a PLS-SEM approach, the impact of complex activity-travel behavior aspects (number of activities in a working tour or in a day) on car choice was studied.

Finally, **chapter 7** combined the 2015 and 2016 multi-days activity-travel datasets in order to quantify the variation in the activity pattern of the workers who faced a workplace relocation. Using GIS techniques as well as a rather unique combined data set, this chapter investigated the impact of workplace decentralization not only on the commuting trip but also on the entire daily mobility.

Based on the previous chapters' findings and conclusions, this chapter summarizes the main conclusions of the whole work, as well as the recommendations and the policy implications that can be implemented in cases of workplace relocation.

## 8.2 Main finding and contributions

A first interesting contribution of this thesis is related to the development of a literature review related to the effect of workplace relocation on travel behaviour. The available literature was vast enough to propose such work. The geographical coverage is impressive even if, for instance, South America or Africa are not represented. The literature shows that while workplace relocation is often associated with a shorter commuting time, car use increase is also frequently reported. However, workplace relocations are all unique and local context may vary importantly. Before and after commuting mode availabilities pay an important role in mode shift even if mode choice inertia is strong.

The quantification of the correlation between stated commuting satisfaction (a proxy for remembered utility) and utility or, to be more precise, the Logsum function of utility (decision utility) constitutes an important scientific finding. While intuitively stated satisfaction and utility Logsum should be highly correlated, it turns out that this correlation reaches 50% and was importantly influenced by context specificities. This potentially can lead to more powerful policy and mobility management strategies as travel behavior shifts may be observed if commuting satisfaction can be significantly improved. On the contrary, overlooking commuting satisfaction deteriorations can lead to many different negative responses from the employees (shift to cars, increased stress and loss of productivity, key employees leaving the job in favour of firm competitors, etc.).

Some methodological contributions have also been done throughout this thesis. The use of Partial Least Square Structural Equation Modelling, and more importantly, the justification for using it over CB-SEM, is an important step forward regarding the use of Structural Equation Modelling approach in travel behaviour analysis. It is expected that, in a close future, researchers will justify their choice of SEM approach (PLS-SEM vs. CB-SEM) and concomitantly the choice of reflective vs. formative latent variables. Additionally, an effort has been made in proposing a comparison between PLS-SEM and Multinomial Logit models. Being very different, the two approaches have been difficult to compare but some criteria have been highlighted to help researchers to select one methodology or the other. As a general recommendation, a SEM-based approach should be adopted when the determinants of certain choices are not sharply defined, hence SEM could potentially be used prior to a DCT approach to identify the most relevant factors and their correlations. This could lead also to a better choice of the type of DCT model (MNL, Nested, Hierarchical, etc.). Although an important methodological advancement is expected by linking SEM and DCT, this was out of scope of this thesis and is left for future studies.

The adoption of Standard Deviational Ellipses modelling to the case of workplace relocation is also deemed to be an important methodological contribution, as through this GIS-based method, employees can be broadly clustered in a limited number of profiles, which are likely to be affected in a significantly different way by workplace relocation. This method has been used to analyse past activity-travel patterns, but it has the potential to be adopted for forecasting the potential long-term changes: employees will try to modify the spatial distribution of the activities within and out of the work-tour in order to efficiently organise their activities within the day (and in non-working days). If workplace relocations will lead to significant and undesired changes in the ellipses, then different changes are expected to be observed, for instance activities anchored to the old work location will be moved either to the new location or near home. In some case, the two anchor points may be modified as well (e.g. changing job or relocating the place of residence).

An interesting, even though secondary, contribution has been made on the possible ways for employers to reach the full potential of travel plans by implementing measures that, at first sight, can hardly be considered as mobility management measures. For instance, propose a fitness room inside workplace might contribute to a decrease of the activity pattern complexity and might, in some cases, lead to car use decrease among the institution workforce.

Because, to the best of our knowledge, no scientific studies have tried to assess the variation of employees' activity pattern after a workplace decentralization, the analysis proposed in this thesis can be seen as an important finding. The fact that, after their workplace decentralization, the vast majority of the travel diary respondents did not anymore performed activities close to their previous worksite indicate that the "Decentralized concentration" planning policy described by Chilla and Schultz (2013) might be effective, at a larger scale, to reduce pressure on Luxembourg-City.

## 8.3 Policy recommendations

Governments seeking to decrease congestion or commuting negative externalities (e.g. pollution) with important firms decentralization process should carefully assess all the possible impacts, both positive and negative. While workplace decentralization is often associated with shorter commuting times which is positive for the concerned workers, less obvious potential effects should not be ignored. For instance, workplace relocation is often associated with higher car use levels, which is, in our sample, associated with lower commuting satisfaction.

Another set of recommendations for authorities promoting decentralization or even institutions searching for a new worksite is related to the moving process strategy. Staff members should be informed reasonably in advance and expectation management strategies should be implemented. Between one and two years do seem to be an appropriate time intervals between the first communication campaign and the effective relocation. This would provide enough time for workers to develop their own adaptation strategies. New recruits have to be informed during this transition period in order to take strategical decisions based on their future workplace, and avoid disappointing surprises when it is too late.

As indicated by Walker et al. (2015) a workplace relocation can be seen as a "window of opportunity for changes" but positive changes in term of modal split can only obtained by investing both time and monetary resources. As indicated by Bamberg (2006), period following life event are suitable for behavioural changes as long as pull measures are implemented to foster individuals towards specific choices.

Because workplace decentralization tends to be associated with shorter commuting times transport engineers or spatial planning authorities might think that, overall, workplace relocations lead to higher individuals' satisfaction levels or an overall increase of well-being. This shortsighted view does not consider that often reduced commuting time after the firm move is obtained thanks to faster mode choices (often shifting to private cars). In our sample, car use was associated with lower satisfaction levels. Additionally, travelling by car in congested networks can be a source of stress and has the potential to negatively affect job productivity and in turn firm business competitiveness, for instance. Consequently, a deep understanding of all the externalities related to workplace relocation is necessary in order to quantify the economic impact.

## 8.4 General conclusions

The overarching research objective was to measure the effect of a workplace relocation on the activity-travel behavior of the concerned employees.

Concerning the commuting modal split, despite that mode choice forecasting estimated a 25% increase of car use (chapter 3), the modal split of the "movers" on their new working site, is only slightly different than the general modal split for the university staff members at the Belval site.

Interestingly, the "movers" and the "newly recruits" exhibit different modal choice for the home-to-work journey and have different commuting distances. Indeed, the newly recruited use less the car (14% difference) than the people who faced a workplace relocation. Actually, the newly recruited have a very similar modal split to the overall University staff members population. On the long run, because of long-term adaptations of the movers (e.g. residential relocation, turnover, etc.), it is expected that the modal split on Belval site will slowly get close to the general modal split.

Regarding the modification of the staff members' activity pattern, analysis of chapter 7 has shown that the staff members' activity spaces have been importantly modified. Clearly, the relocation of their workplace has led travel diary respondents to modify their entire activity space. Interestingly, only few respondents (9%) had again activities in the neighborhoods of their previous workplace (Walferdange campus). To a certain extent, the "decentralized concentration" seem to be effective in decreasing the pressure (in terms of trips done) in Luxembourg City.

Of course, the distance between the old and the new workplace is a key element. With similar local context (PT & road accessibility, parking provision), a workplace relocation of 2km or 50km will certainly not have the same effect!

## 8.5 Future research directions

While this thesis has largely covered the effect of workplace relocation on activity-travel behavior, it also opens several research paths.

The literature review proposed in chapter 2 has identified research gaps that are still worth being investigated. For instance, no scientific studies have succeeded in collecting information on the reason and importance of pre-relocation turnover. It might simply be short-term contracts reaching their end, employees leaving their institutions for personal reasons or more problematically, employees quitting their current job because of the workplace relocation. An interesting general research question that can be proposed for future studies is 'which long-term changes are expected by a specific workplace relocation, and when are these changes expected to be observed by an employee?'. This certainly relates to a broad area of research in travel behavior, which focusses on studying the windows of opportunities due to major life events, which are advocated to be ideal moments to induce change in travel behavior inertia attitudes.

The work related to commuting satisfaction should be expended to further identify its determinants. Moreover, the work done in this thesis should be better casted in the more general research undertaken in the past on happiness and well-being. Commuting satisfaction was treated in this thesis as an indicator of potential short and long-term adaptations. However, this assumption remains rather complex and needs to be further investigated. A possible way to study this hypothesis would be to use panel data where information regarding individuals commuting satisfaction is collected. The findings of this thesis will be fundamental to design the surveys and formulate the questions in the most relevant way, especially considering the large number of determinants that can potentially be connected to commuting satisfaction.

The use of PLS-SEM in chapters 5 and 6 is rather innovative in travel behavior analysis and will definitely deserve further research. Additional investigations are needed to assess the efficiency and robustness of

PLS-SEM over CB-SEM. Moreover, the SEM theory is still under-explored in the transportation field, and different variants are still to be consolidated (e.g. multi-level SEM). Moreover, as indicated previously, SEM represents a perhaps more reliable and powerful way of doing a factorial analysis and hence to identify the travel choice determinants and their relations, which can help at specifying the best form of a Discrete Choice Model and the attributes to be calibrated in the systematic utility components.

Finally, the adoption of the Standard Deviational Ellipses has been shown to have potential for quantifying the impact of workplace relocation on the spatial distribution of daily and weekly activities in relation to the mutual location of home and work places. While exploratory analysis on a small database has allowed profiling the respondents and draw conclusions on the changes in their activity-travel patterns, the available database does not allow to generalize the conclusions and go further in using the approach for predicting future spatial changes.

Overall, the conclusions and findings of this work should be seen as general guidelines to perform future studies, where more effort should be spent on collecting multi-day surveys with a more statistically significant number of respondents, as well as the time between the collection of different longitudinal datasets should be more carefully defined.

Future research should ultimately provide a more thorough link between the observed effects of workplace relocation and the various possible transport policy and mobility management measures that can be adopted to manage the event.