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Assessing the impact of internal migration on travel demand in Flanders using an Activity-based model

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Eridona Selita,

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Abstract

Following the considerable attention of activity-based models in transportation planning and forecasting, and the necessity to understand and reveal the impacts of transportation policies, this paper aims to simulate and examine a population policy scenario. It explicitly uses FEATHERS, a demand-side activity-based model, operational for Flanders, Belgium. The ABM is required to estimate how the interzonal migration of Flanders'population from small rural towns to large, urbanized city areas closely affects the daily activity and travel choices of the individuals. The methodology consists of a classification of FEATHERS zoning system based on the urbanization degree of Flanders, where the traffic analysis zones (TAZs) belonging to the Flemish Diamond, (comprising Brussels, Ghent, Antwerp, and Leuven) are categorized as urban and others as rural. This categorization is used to spatially redistribute the population of Flanders from rural to urban zones by 2%, 5% and 10% with equal proportions. Then, the FEATHERS simulation framework is exploited for executing a current baseline scenario and three migration scenarios. It simulates resident's activity and travel decisions in a day unit and provides the results in the form of activity-travel diaries. They suggest a noticeable impact on the activity- travel related attributes of both zones after the implementation of the policy scenarios. There is a prominent modal shift toward car as the main mode of travel in urban zones and during peak hours, whereas a slight increase in public transport and car sharing is found in rural zones. Changes in the activity choice are deemed as well. There is an increase in the frequency of trips for home-based activities in urban areas and work-based activities in rural zones. Nevertheless, car remains the dominant mode for all types of activities. Last but certainly not least, the vehicle kilometres and hours travelled are scrutinized as well. Following the patterns of the modal shift and trip frequency analysed, there is an increment of VKT and VHT in urban zones whilst the opposite takes place in rural zones. Intuitively, one could have expected the opposite to happen in both zones after the execution of the migration scenarios. Furthermore, the findings in the literature also indicate a reverse effect on the transportation demand of rural and urban zones when more individuals are relocated to large, urbanized zones. Therefore, many of the results from this research are indicative rather than conclusive. To ultimately improve the quality of this research and provide conclusive results of a greater extent, more cross-validation needs to be done by further validating the FEATHERS model calibration and output stability.

Keywords

Activity-based models; policy evaluation; travel demand measures; interzonal migration; Flanders region; policy scenario sensitivity

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List of abbreviations

ABM	Activity-based Model
DTs	Decision Trees
FEATHERS	Forecasting Evolutionary Activity-Travel of Household and their Environmental RepercussionS
OD	Origin- Destination
OSM	OpenStreetMap
PT	Public Transport
QGIS	Quantum Geographic Information System
TAZs	Traffic Analysis Zones
TDM	Travel demand measures
VHT	Vehicle hours travelled
VKT	Vehicle kilometres travelled

1 Introduction

1.1 Background and rationale for the study

Activity-based models (ABM) of travel demand have received substantial attention in transportation planning and policy due to the growing complexity of activity and travel patterns of individuals nowadays. Considering that these approaches adopt a holistic framework by taking into account the individual interactions in different socio-demographic contexts and spatiotemporal constraints, they explicitly assist in understanding travel behavior and forecast transport demand. The activity-based models have been widely used in practice since the 90s. Specifically to evaluate the impact of innovative policies and to address critical problems, such as environmental issues (energy consumption and greenhouse gas emissions), social matters (traffic congestion, degradation of human health, and traffic accidents), and economic issues (sustainable economic growth and cost-effective options).

In contrast with the conventional trip-based and tour-based modeling methods, researchers argue that these models count numerous advantages and offer a richer framework. ABM identifies travel as a derived demand for performing personal activities ((Ben-Akiva and Bowman, 1998) and, therefore, portrays the whole picture of an individual's activities meanwhile accounting for trade-offs among various activities and travel alternatives in one's daily activity pattern. The linkage among activities and travel for an individual and other multiple persons in the household makes the models more realistic, known in transportation as behavioral realism. Undoubtedly, this enables a more accurate representation of the travel conditions on activity and travel choices. Following this line of thought, (Delhoum et al., 2020) consider these models significantly advanced since they can incorporate the influence of very detailed person-level and household-level attributes and the ability to produce detailed information across a broader set of performance metrics. All in all, what Delhourm implies is that such optimization allows the models to be flexible and serve multidisciplinary approaches.

In an attempt to understand the application of such models, previous research reviewed for this thesis revealed the utilization of different activity-based models for evaluating various travel demand measures (TDMs) and assessing more complex transportation projects, plans and policies. In general terms, (Arentze et al., 2008) claim that there is sufficient evidence where activity-based models have proved sensitive to a broader range of policy issues. Today, many such models operate successfully, and new ones are also being developed. Despite the level of enhancement and the computational complexity involved, all models aim to facilitate decision-making in the system, especially for those developing transportation policy.

1.2 Problem statement

The review of activity-based approaches indicates the substantial importance that the models have gained in the transportation sector over the years. One of the main drives for the development of ABM is to provide a model with a high resolution of sensitivity towards policy scenarios that are generally important in planning and policymaking.

In the transportation sector, there is a growing need from policymakers to opt for a better design of new policies, as well as to verify the effectiveness of the current transport policies in place. For such purposes, researchers tend to simulate and examine different policies using activity-based models and therefore identify and estimate changes in response to them. Although policy needs can vary from region to region, (Shiftan & Ben- Akiva, 2010) stresses that there is a minimum set of policies to which these models should and can be sensitive. Demand management (i.e., parking restriction, congestion pricing) and land-use policies (i.e., mixed development, pedestrian-friendly site design) are among the most crucial when considering possible policies or scenarios to be evaluated.

While there has been serious consideration toward simulating, analyzing, and evaluating population policy scenarios, few attempts have been made to investigate quantitively the effect of interzonal migration on the activity-travel choices of individuals. As (Lyu et al., 2019) highlight, rural to urban migration is a well-known phenomenon globally. Traditionally, people migrated from rural zones to zones with a higher degree of urbanization in the hope of gaining a better standard of living and cherishing the new prospects. This residential relocation, however, imposes sustained pressure on the major cities to satisfy the increased social, economic, and transport infrastructure needs. The new conditions explicitly influence people’s activity and travel behavior patterns.

1.3 Scope and research objectives

Given the importance and steady growth of transport policies worldwide alongside the benefits of the activity-based models, as mentioned earlier, there is enough motivation for testing and evaluating the impacts of policy scenarios by taking advantage of the sensitivity analysis of an activity-based model.

Therefore, central for this research – which also forms the main objective behind it – is to observe and understand how the migration of the Flanders[1]’ population from small towns/villages to large urbanized city areas closely affects the daily activity-travel choices of the individuals. The policy scenario is assessed using FEATHERS, a calibrated and readily applicable activity-based model

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[1] Region in Belgium

for Flanders. More specifically, a null and three migration scenarios are executed by using two methodologies:

1. data preparation and manipulation
2. microsimulation model technique

This study is an assessment exercise that illustrates the different impacts in travel demand when the synthetic population is spatially and randomly redistributed from rural zones of Flanders to urban zones of the Flemish Diamond[2] by 2%, 5% and 10% with equal proportions.

The main research question is broken down into several sub-questions, which, when analyzed step-by-step, will form a better understanding of the main objective. Central for this study are the following sub-questions:

- What are the associations between migration from rural to urban areas and activity- travel behavior found in empirical studies?
- Given the use of an updated synthetic data population, to what extent can we detect an influence of the migration component?
- What are the differences between scenarios in terms of activity and travel behaviour?
- Which explanatory attributes provide significant information after the execution of the scenarios?
- What is the level of consistency between scenarios and selected attributes for analysis?
- Are the results obtained plausible with previous research in the literature?

To reach the main objective, four specific goals are required to be accomplished:

- to take full advantage of the FEATHERS activity-based model so that it can derive the impacts of the migration scenarios;
- to demonstrate how the internal migration from rural to urban zones in Flanders influences activity and travel-related decisions;
- to assess which travel demand attributes incur a considerable impact after the execution of the scenarios;
- to verify if the output derived from the scenarios executed in the model, is plausible with the expectations and previous research.

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[2] Flemish network of four metropolitan areas in Belgium

1.4 Thesis Outline

Excluding the introductory chapter, which provides a rough description of the problem and research aims, this dissertation comes in six parts.

The following section introduces the reader to a succinct overview of the recent literature on the state-of-the-art of activity-based models, their benefits in travel demand modelling and their applications in assessing different transport policies and scenarios from a global perspective. Chapter 3 provides a conceptual understanding of the framework of FEATHERS, the demand-side ABM that is used for the purpose of this research. In the same chapter, the relevance of the model along with a description of the modelling inputs and how FEATHERS take decisions about activity-travel related matters of an individual is presented.

Moving forward, chapter 4 is dedicated to the presentation of the case study, which sets the scene in the Flanders region of Belgium. It further elaborates on the reasons why the specific study zones were selected and the motivation to perform analysis over the interzonal migration of Flanders and its impact on the activity-travel patterns. Whilst, In the fifth chapter, the research design and methodology used to develop this study are discussed. This section of the dissertation aims also at justifying the use of the methods and why they are better suited for such a research. Whilst the sixth chapter lays out the output and findings from the FEATHERS model simulation. To get a clearer overview of the impact of the policy scenario, a brief comparison between null and migration scenarios is depicted.

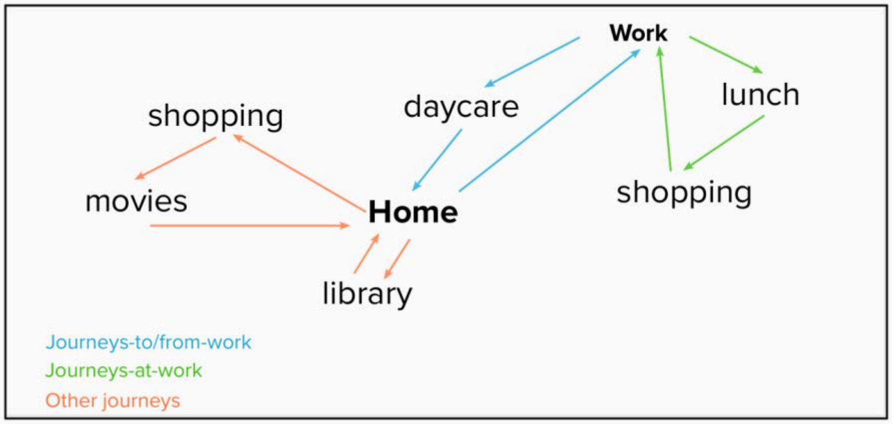
The findings of the results are validated against prior research in the last chapter. This chapter also provides, in a nutshell, the conclusions and future research areas to further expand this study.

2 Approaches to travel demand modelling

2.1 Why Activity-based model?

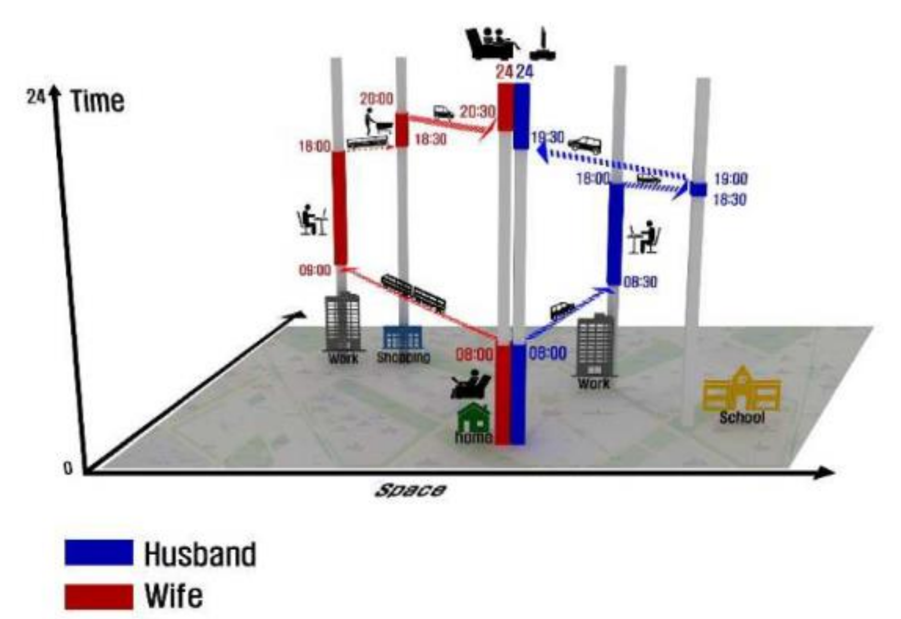
Although the four-step framework has been successfully merged into certain new modeling approaches, the most common trend toward addressing travel-related concerns is to shift toward activity-based model frameworks. Aiming to provide a rational explanation as to why the activity-based models can and should be used for studying and assessing policy impacts, it is essential to provide further insights on their benefits. The discussion of Trip-based versus Activity-based models dates for more than a decade, where transport modelers and planners in the jurisdiction share different views about the willingness to pursue any of the models in practice. Nevertheless, they concur that the true advantage of the activity-based approach is that it is sufficiently sensitive to a broad range of scenarios that are generally important in transport planning and policymaking (Arentze & Timmermans, 2005) stresses. This is mainly due to the following reasons:

1. Using tour concepts as in Figure 1 to portray how trips are coordinated and scheduled, recognizing the inter-trip dependence;
2. Spatial, temporal, and modal consistency between trips made by the same person during the course of a day and within the same tour;
3. Motivation for travel in activity participation, thereby allowing substitution between travel and non-travel means of meeting personal and household needs;
4. Representation of both long-term and short-term decision perspectives;
5. Effects of accessibility on travel generation (e.g., congestion, urban form, and activity opportunities;
6. Simulation of the activity-travel decisions and schedules of individual households and of particular individuals as represented in Figure 2.



Source: Own elaboration

Figure 1. Example of "Tours"



Source: (Eom et al., 2020)

Figure 2. Example activity-travel schedule of individuals in a household

Overall, the primary benefit of activity-based models is that these models reduce conventional model insensitivity by tracking the factors that influence trip-making patterns and behavior more precisely. In essence, the level of specificity that activity-based models offer with respect to variations in acceptable travel cost trade-offs across the population makes these models particularly well suited for testing policy alternatives or transportation demand management strategies. The household-based structure of ABM and the desirability of using extremely disaggregated input data make the model a more comprehensive policy analysis tool rather than simply a traffic volume generator. However, (VDOT, 2009) stresses that the primary penalty for using this more detailed approach is a more complicated model.

2.2 Overview of Activity-based travel demand models: A brief comparison

Over the years, activity-based models have evolved from the two main groups: Utility maximization-based econometric models and rule-based computational process models (CPM), into more developed and more computationally complex models. Examples include agent-based, and time-space prism approaches. While an agent-based approach allows agents to learn, modify, and improve their interactions with other agents and their dynamic environment, time-space prisms are utilized to capture spatial and temporal constraints under which individuals construct the patterns of their activities (Tajaddini et al., 2020). Numerous studies have systematically reviewed the progress and development of the ABM travel demand models over time. Therefore, Table 1 summarizes the evidence found on the evolution of these models by also pointing out their limitations. The literature highlights that the major limitation - which also forms the most significant challenge - is the incomplete reflection of behavioural realism.

Table 1. ABM evolution over time.

ABM type & year of proposal	Models	Model limitations	Publication
Constraint-based models *1967*	PESASP	Consider only individual accessibility, rather than household-level accessibility	(Lenntorp, 1976)
	CARLA		(Jones et al.,1983)
	BSP		(Huigen, 1986)
	MAGIC	Some system features, like open hoursand travel times, are considered fixed	(Dijst & Vidakovic, 1997)
	GISICAS		(Kwan, 1997)
Utility maximization-based models *1978*	Portland METRO	Assume that all decision-makers are fully rational utility maximizers which are not realistic in practice	(Bradley et al., 1998)
	San Francisco SFCTA		(Bradley et al., 2001)
	New York NYMTC	Unable to reflect latent behavioral mechanisms in the decision processes	(Vovsha et al., 2002)
	Columbus MORPC		(Consult, 2005)
	Sacramento SACOG		(Bowman & Bradley, 2005)
	CEMDAP		(Bhat et al., 2004)
	FAMOS		(Pendyala et al., 2005)
	CT-RAMP		(Davidson et al., 2010)

Computational process models *2000*	ALBATROSS	Focus more on scheduling and sequencing of activities than the underlying rules in decision-making	(Arentze & Timmermans, 2000)
	TASHA		(Miller & Roorda, 2003)
	ADAPTS		(Auld & Mohamadian, 2009)
	FEATHERS		(Bellemans et al., 2010)
Agent-based modeling *2004*	ALBATROSS	High computational complexity	(Arentze & Timmermans, 2004)
	FEATHERS	No transparency in the mechanical process of agents interacting with other agents and environment which depends on the parameters'values	(Bellemans et al., 2010)
	MATsim		(Balmer et al., 2006)
	TRANSIMS		(Nagel et al, 1999)
	SimMobilitiy	Requires well-defined conditionsand constraints	(Adnan et al., 2016)
	POLARIS	Non-reproducibility due to the non-streamlined process of calibrating and imputing parameters for the models	(Auld et al., 2016)

Source: Own elaboration based on (Tajaddini et al., 2020)

2.3 Travel demand management applications in ABM

To increase the efficiency of the transport systems, travel demand management (TDM) strategies are continuously tailored and implemented. However, to measure the effectiveness of such strategies even before implementation, it is crucial to initially apply them to activity-based models to derive their impact(s). Literature shows enough evidence of such strategies applied by different researchers and academics, as displayed in Table 2. Examples include mode shift strategies (encourage the shift towards more sustainable modes, ride in off-peak hours, congestion pricing, etc.), shared mobility (car-sharing), telecommuting, increasing the fuel price, etc. All these policy scenarios/strategies were mainly examined using activity-based models that were operational in the research area.

Table 2. Travel demand management policies within the activity-based platform.

TDM Strategies	**Publication**
Mode shift	(Adnan et al., 2020)
Congestion pricing	(Shiftan & Suhrbier, 2002)
Shared mobility	(Balac et al., 2017); (Cepolina & Farina, 2012)
Teleworking	(Bellemans et al., 2015); (Pirdavani et al., 2014)
Parking price strategies	(Ciari et al., 2017)

Source: Own elaboration based on (Tajaddini et al., 2020)

To end this chapter, it is critical to emphasize that the decision to embark on activity-based model sensitivity analysis should not be taken lightly. Travel forecasting is a challenging endeavour regardless of the modeling framework. Preparing input data, summarizing output data, and executing the model certainly take longer, which is the case of our activity-based model as well. But the interpretation of ABM results is also more difficult because the causes and effects must be traced through a much longer chain of model elements, and like any modeling system, a full awareness of all the dynamics at work within the procedures by any one person is impossible. Therefore, when performing sensitivity analysis, it is often required to rely on an abstract understanding of the model formulation and interpretive value judgments to explain the results.

3 About FEATHERS

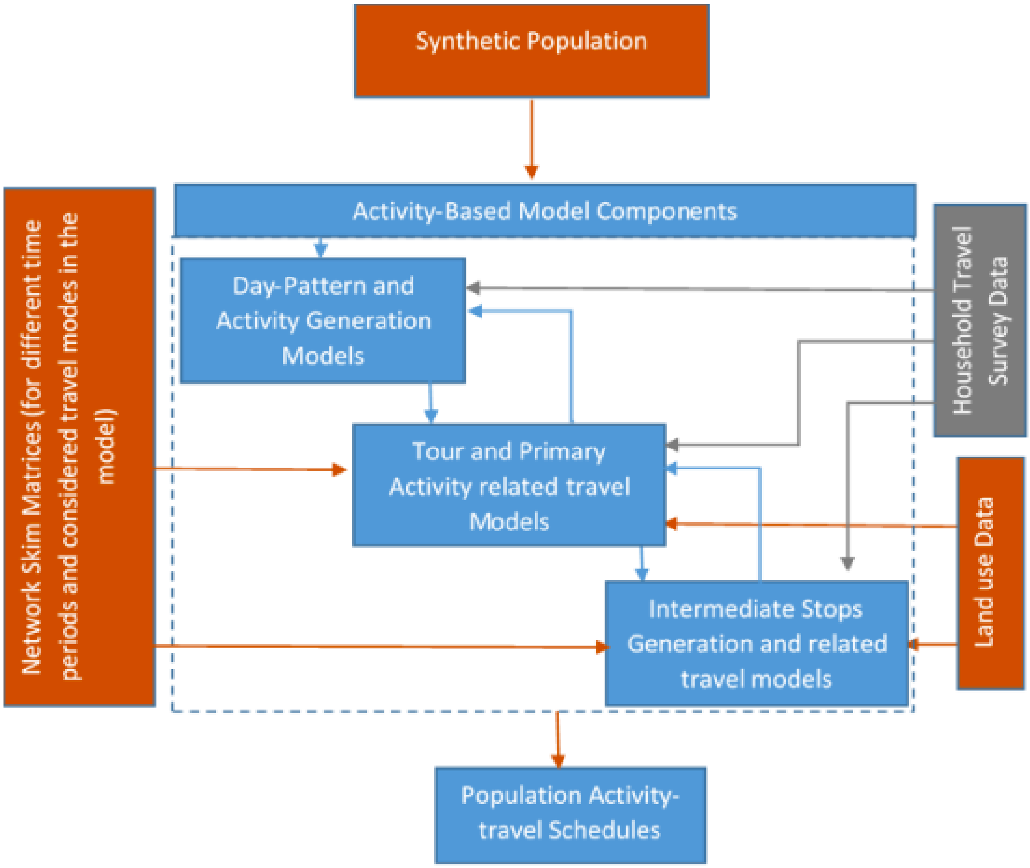
FEATHERS (The Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS), is a micro-simulation framework developed by the Transportation Research Institute (IMOB) of Hasselt University, Belgium, to facilitate the implementation of activity-based models for travel demand forecasting as the founder (Bellemans et al., 2010) indicates. The model is fully operational for the Flemish Region and the Brussels-Capital Region of Belgium (hereafter, we refer to Flanders for short). Since its birth, continuous efforts have been made to innovate this framework's methodological and practical applications. (Bao, 2016) claims that the primary goal of the FEATHERS framework is to allow, on the one hand, for easy updating and/or replacement of functionalities used in activity-based models since the state-of-the-art in the activity-based research field progresses rapidly nowadays, and on the other hand, for the practical use of the system by practitioners and end-users. Furthermore, (Kochan, 2012) asserts that in FEATHERS, it is possible to implement large-scale activity-based transportation simulations alongside methods to analyze the output generated from it.

3.1 Relevance of the model

Being a state-of-the-art activity-based transport model, FEATHERS can easily tackle several transport demand management strategies and policy scenarios. In line with this, it is open wide for introducing extra sub-models, which can lead to even more detailed transport modeling. Being a modern transport model, FEATHERS can also be used as a starting point for integration with other models such as emissions, traffic safety, and electrification. (Adnan, 2018) proved the success of FEATHERS when merged with a supply counterpart, specifically MATSIM, to assess a variety of policy scenarios such as: restricting car use in core city areas, road pricing, teleworking, parking regulations, etc. This model validation (FEATHERS + MATSIM) demonstrates the success of the demand model as a stand-alone and as an integrated model as well. Moreover, it makes ample room for assessing other policy scenarios that are emerging nowadays.

3.2 The FEATHERS Framework

It is essential to outline the overall framework and model structure of FEATHERS so as to deliver an easy comprehension of its functionalities. The framework is composed of various models and sub-models interconnected with each other, which predict the different daily activity and travel decisions, otherwise defined as mid-term decisions. Specifically, FEATHERS is a highly advanced disaggregated travel demand framework designed to model mid-term decisions. Figure 3 shows the model components and process flow of a typical ABM and FEATHERS, respectively.



Source: (Adnan, 2018)

Figure 3. FEATHERS Model System with Required Modelling and simulation Inputs

3.2.1 The data available

A synthetic population with known sociodemographic characteristics of the Flanders region is an input to the system. Synthetic population and the other inputs such as network skims, land use characteristics, etc. are discussed more in detail below:

1. **Synthetic population** is the primary data for being able to execute the simulation. This data is typically created through iterative proportional fitting (IPF) algorithms, a technique used to generate and estimate the distribution of demographic characteristics such as age, gender, work status, car ownership, driver license ownership, vehicle kilometers, etc. Therefore, each synthetic household and its members have many clearly defined characteristics for use in the model system as shown in Table 3.
2. **Household travel survey data** is the main data source for modelling purposes. It generally contains information on the individual and household level socio-economic attributes (also part of synthetic population) and also travels details of the individuals, e.g. where they have traveled in the region, which activities they have performed in a given day, how (travel mode) and when (time of the day) they have traveled. This is also the case for the Flanders

region household travel data. Onderzoek Verplaatsingsgedrag 5 (OVG), which translates to research on travel behavior, is typically conducted every four years by the Flemish government to enrich and update the information on the population in Flanders.

3. **Land use data** is crucial for modelling the destination choice of activities. Every destination choice in FEATHERS is based on Flanders's traffic analysis zones (TAZ). Each TAZ is linked to a list of land use parameters such as the number of schools, shops, recreational places, etc as portrayed in Table 4. More information about TAZ is given in the following section.
4. **Network skims** provide information on the level of service (zone-zone travel time, travel distance, travel cost, etc.). FEATHERS is fed with travel time matrices (or skims) for a small number of pre-determined time windows, such as AM peak, PM peak, and off-peak.

Table 3. Example of attributes for each agent in the synthetic population

Characteristic type	Attribute	Values
Individual Level	Gender	male; female
	Age class	0-5; 6-17; 18-39; 40-59; 60+
	Age	an integer from 0 to 110
	Socio-professional status	student; active; inactive
	Education level	primary; high school; higher education; none
	Driving license ownership	yes; no
Household Level	Type	single man alone; single woman alone; single man with children (and other adults); single woman with children (and other adults); couple without children (and other adults); couple with children (and other adults)
	Number of children	0 to 5
	Number of other adults	0 to 2
	Number of vehicles (cars)	0 to 3+
	Household location	TAZ in the study area

Source: Own elaboration based on (Adnan, 2018)

Table 4. Example of attributes for each agent in the land use and household travel data

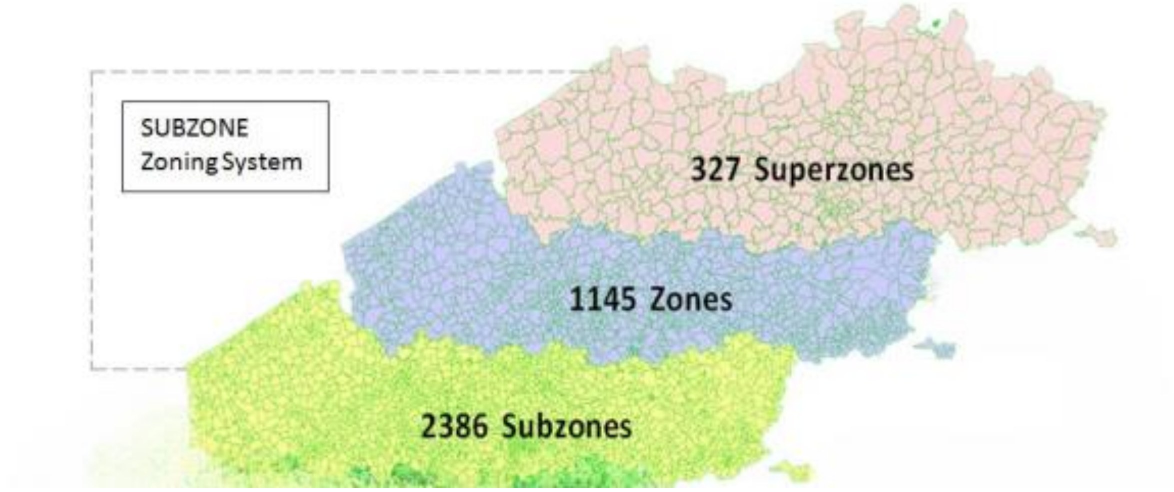
Characteristic type	Attribute	Values
Household travel data	Activity type	home; work; business; bring-get; education; shopping; others
	Activity location	TAZ in the study area
	Activity start time	minutes since midnight
	Activity duration	minutes
	Trip mode	micro 5 km/h (e.g., walk); micro 15 km/h (e.g bike, step-scooter); micro 25 km/h (e.g., e-bike, motorscooter); private (e.g., car driver);

		shared private (e.g., car passenger); shared on-demand (e.g., minibus, shared taxi); shared traditional (e.g., public transport: bus, tram, metro, train)
	Trip origin	TAZ in the study area
	Trip destination	TAZ in the study area
	Trip start time	minutes since midnight
	Trip duration	minutes since midnight
Land use data	Subzone	an integer from 0 to 2385
	Superzone	0 to 327 municipalities in Flanders
	Urbanization degree	an integer from 0 to 31232
	Shops (open at night)	an integer from 0 to 2774
	Shops (open at day)	an integer from 0 to 2774
	HORECA	an integer from 1 to 1256
	Number of total workers in the zone	an integer from 0 to 33337
	Number of total students in the zone	an integer from 0 to 12325

Source: Own elaboration

3.2.2 Zoning system

Currently, the FEATHERS framework is operational in the so-called Subzone zoning system, defined as a spatial hierarchy composed of three layers. In order of increasing detail, there are Superzones (compatible with 327 municipalities of Flanders), Zone (consisting of 1145 administrative units lower than municipality), and Subzone (composed of 2386 virtual areas according to homogenous characteristics with an average size of 5,8 km^2) as in Figure 4.



Source: Own elaboration based on (Bao, 2016)

Figure 4. Levels of geographic detail of Flanders

Each zone at a lower level (more detail) belongs to only one zone at a higher level (less detail), as portrayed in the table below. For this research, the subzone geographical unit is used to redistribute the population from rural to urban zones with equal proportions, once the zones have been categorized with respect to their degree of urbanization.

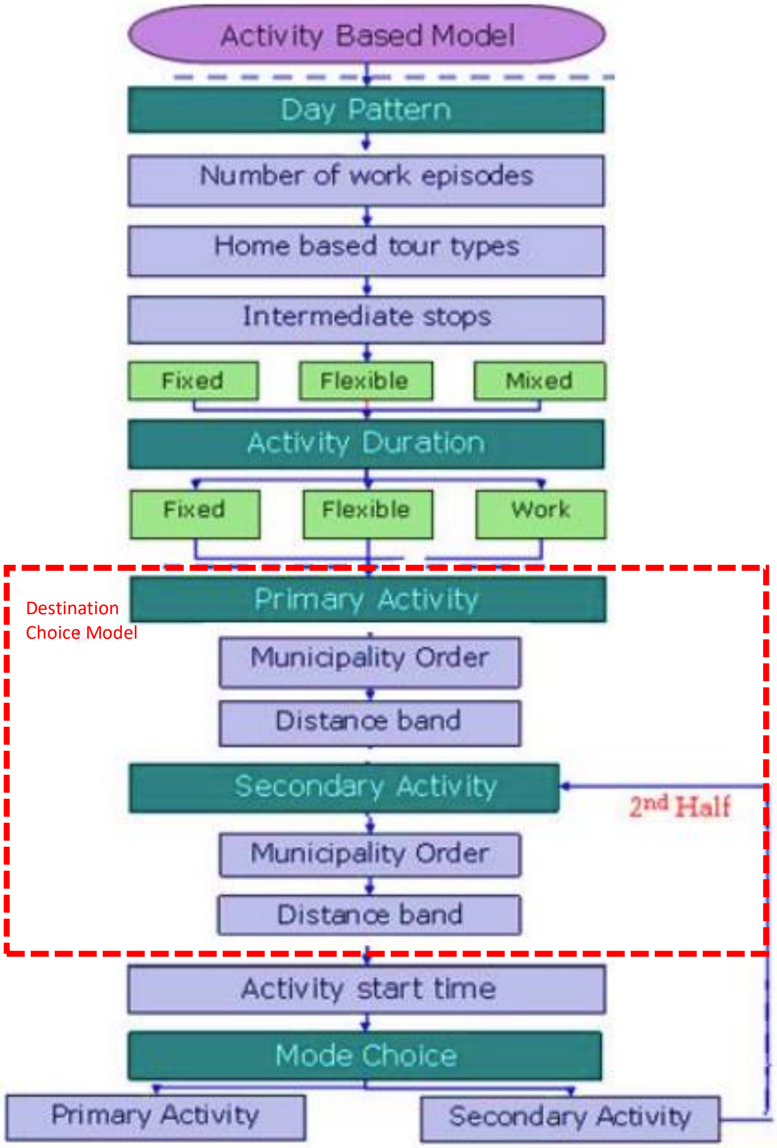
Table 5. The hierarchical structure of the Subzone zoning system in FEATHERS

Hierarchy of Subzone zoning system		
Superzone ID	Zone ID	Subzone ID
1	1	1
		2
		:
	2	4
		5
		:
2	10	27
		28
		:
	11	:
		:
		:
:	:	:
		:
		:
327	1144	:
		:
		:
	1145	:
		2385
		2386

Source: (Bao, 2016)

3.3 How FEATHERS works?

The real-life representation of Flanders is embedded in an agent-based simulation model, known as FEATHERS, which consists of over six million agents, each agent representing one member of the Flemish population. The activity-travel framework of the model simulates resident's activity and travel decisions in a day unit. To have a comprehensive understanding of the way FEATHERS works, its modelling components are shown on Figure 5 below.



Source: (Adnan, 2018)

Figure 5. FEATHERS Schematic Framework for Key Scheduling Models

As a first step, the number of work episodes followed by the home-based tours are determined within the day pattern model. Then, intermediate activities along with their location (i.e. before or after the tour's primary activity) are determined for each tour. The intermediate activities are categorized as fixed [bring, get, other] or flexible [shopping, services, social, leisure and touring]. The next step after having each activity in the schedule determined, its duration is modeled. For the destination choice model, a multi-level decision hierarchy is used to specify the location of an activity. A traffic analysis zone is randomly selected within the predicted distance band. The last step before the mode choice is the activity start time hour. At this stage, only the hour when the activities will take place is determined, while exact timings are only available once all the decisions have been made. The concluding step is related to the transport mode choice for each activity.

All in all, decisions are based on several attributes of the individual (e.g., age, gender), of the household (e.g., number of cars), and of the geographical zone (e.g., population density, number of shops). For each individual (i.e. a member of the synthetic population with a specific identifier), the model simulates whether an activity (e.g., shopping, working, leisure activity, etc.) will be carried out or not. Subsequently, the location, duration of the activity and transport mode are determined.

3.3.1 FEATHERS sub-models

FEATHERS is a rule-based ABM that relies on Household travel data for formulating rules (Bellemans et al., 2010). Each sub-model in FEATHERS is built using a Decision Trees (DT) approach that have been trained on the OVG[3] (Onderzoek Verplaatsingsgedrag Vlaanderen) dataset, the official Flemish household travel survey. (Adnan, 2018) states that these DT can be considered as a cost/utility function involved within FEATHERS. They are developed by recursively splitting a sample of observations into increasingly homogeneous groups in terms of a given response variable. Furthermore, FEATHERS utilizes the Chi-square automatic interaction detection (CHAID) algorithm which evaluates splits based on a Chi-squared measure of significance of differences in the response of the distribution between groups.

An example is provided in Figure 6 aiming to briefly illustrate the DT procedure involved in ABMs. Nevertheless, it is crucial to note that FEATHERS is composed of DTs way more complex than the one portrayed below as it considers a wide menu of variables from different data sources. The illustration begins from the travel related attribute such as travel cost/km (which has been decided from the earlier model in the decision hierarchy) and then based on socio-economic characteristics of an individual and household (available from the synthetic population), the tree decides which travel mode is more reasonable.

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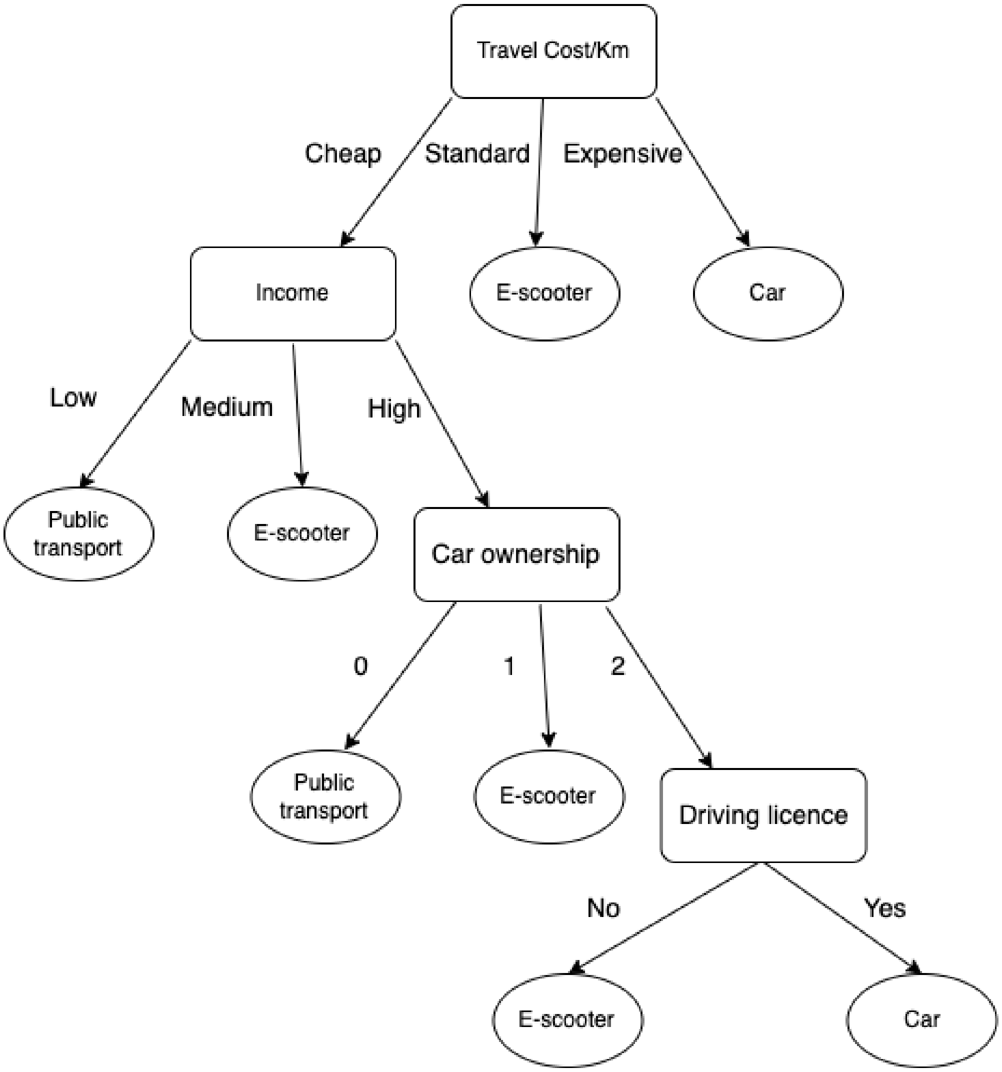
[3] https://www.vlaanderen.be/mobiliteit-en-openbare-werken/onderzoek-verplaatsingsgedrag-vlaanderen-ovg

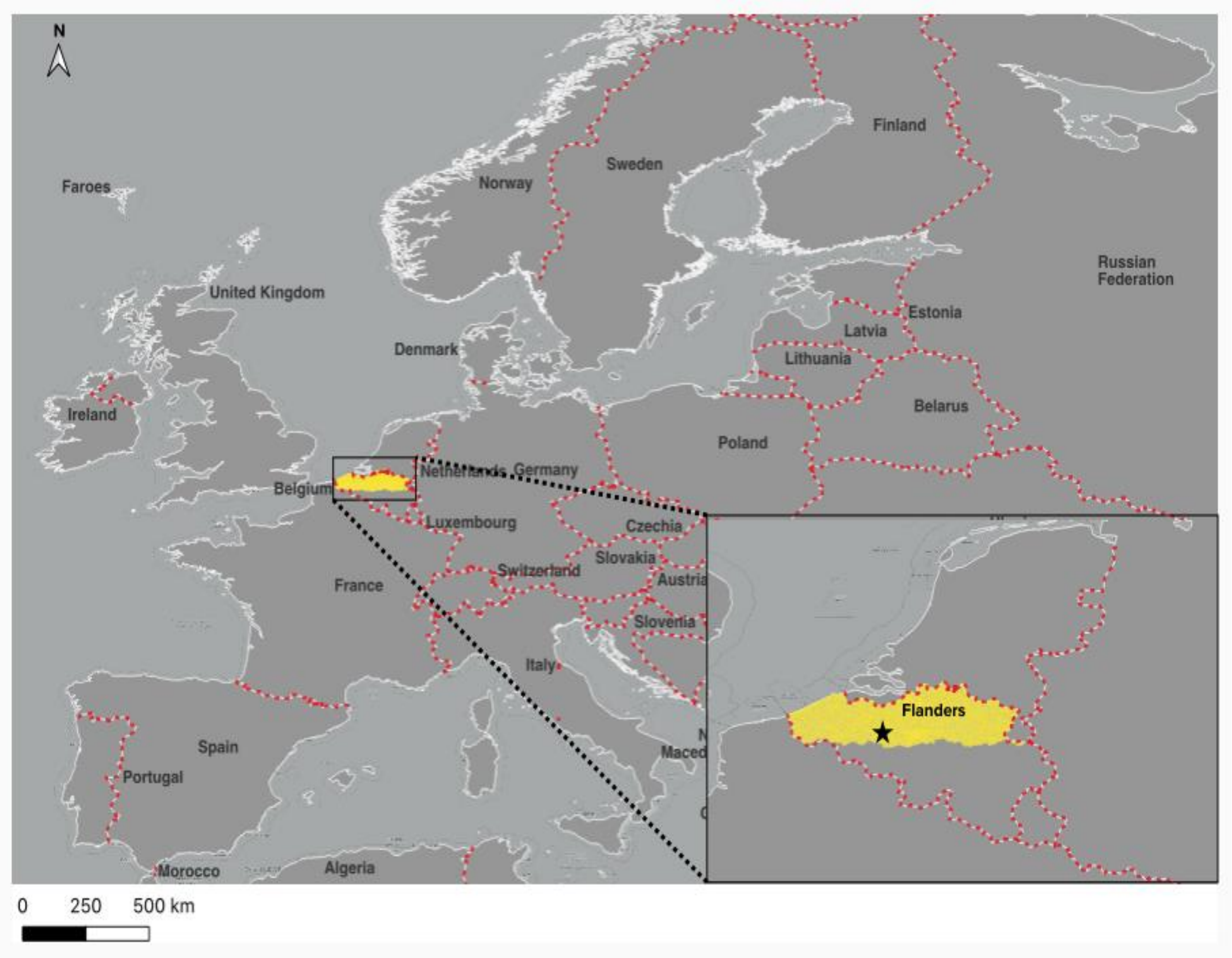


Source: Own elaboration based on (Adnan, 2018)

Figure 6. Decision trees for travel mode choice

4 Case study: Flanders Region

As earlier mentioned, FEATHERS is an activity-based model fully operational at the level of Flanders; hence, the region will serve as the study area for executing the policy scenario. Several successful examples of similar TDM policy scenarios for the Flanders region can be found in the history of FEATHERS application. For example, the briefing from (Adnan, 2018) as a compliance for the iSCAPE H2020 project, reviews and examines a wide range of scenarios in specific areas of Flanders. Furthermore, (Pirdavani et al., 2015) demonstrate the efficacy of two TDM scenarios (teleworking and fuel-cost increase) - further elaborated below - in the Dutch-speaking region of northern Belgium, Flanders. The case study is set up to provide with the necessary insights on the context of this research, in a way that accurately reflects the impacts of the null and future migration scenarios. Figure 7 presents the situation of the study area.



Source: Own elaboration

Figure 7. The situation of the study area

Flanders, despite not being the largest region of Belgium by area, it is the region with the largest population if Brussels is included. The area of today's Flanders, by every definition, has figured prominently in European history since the Middle Ages. The geographically flat area is composed of five easily accessible provinces, each with its own provincial capital, not including Brussels. As of today, there are a total of 500 municipalities in the Flemish region of Belgium, which constitute the focus of the most prominent economic region within the country. The region 'strategic central location is a key performance indicator for the region's competitiveness in the European market. Ghent, Antwerp, and Leuven are the largest cities of Flanders if Brussels is not considered.

4.1 Selection of study areas

To test the migration scenarios through the framework of FEATHERS, large urban municipalities in Flanders are defined as study areas. The municipalities of Brussels, Ghent, Antwerp, and Leuven have the following properties:

1. Are medium- large size cities with a population with a population from 0,5 -2 million
2. Population density varies between 400 persons/km^2 to 1000 persons/km^2
3. Are major economic, recreational, and educational hubs within Belgium and Europe
4. Are trip attractor and trip generator themselves

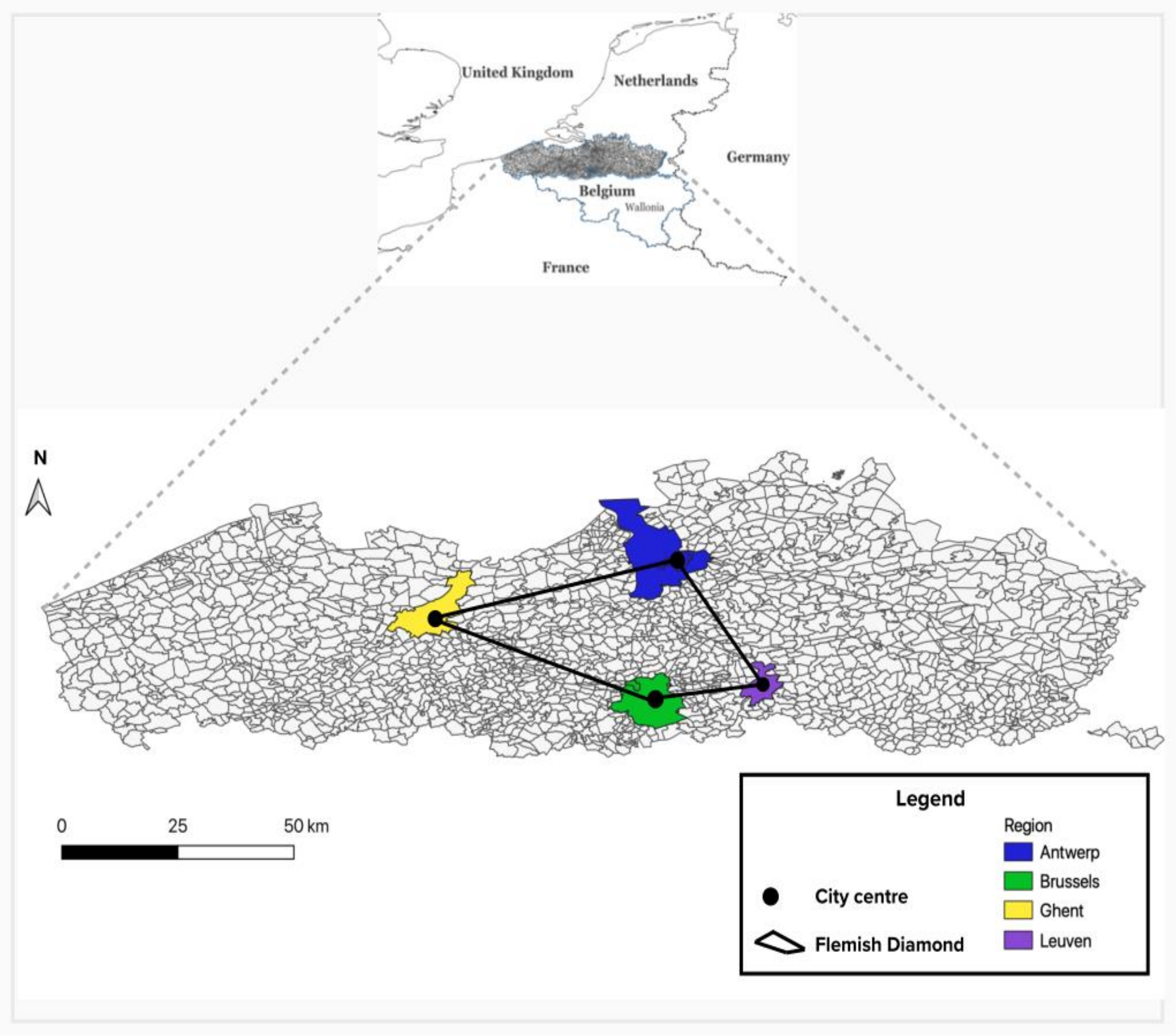
The details and the significance of these zones to test the intended policy scenario are further defined below.

4.2 Motivation for conducting migration analysis

4.2.1 Detecting urban sprawl

At the country level, Belgium was found to be the European country with the highest degree of urban sprawl (EEA report on Urban sprawl in Europe, 2016) and this phenomenon is most pronounced in Flanders. Based on recent studies, Flanders is one of the most densely built and inhabited regions in Europe, due to urbanization. The densely populated area (515 inhabitant/km^2) shows a very scattered urbanization pattern, which originates from the medieval settlement structure. Furthermore, the highest population density is found in the area circumscribed by the Brussels – Ghent – Antwerp – Leuven agglomerations that is known as the "Flemish Diamond". In other words, it is a polynucleated urban system which concentrates high-quality industrial, commercial, service, logistic and research activities and is the main centre of economic development in the Flanders–Brussels region (Poelmans & Rompaey, 2009). The name is derived from that the four agglomerations form the four corners of an abstract diamond shape as presented in the figure below. Although the Flemish Diamond is a regional government concept not officially recognized by the Belgian central authority, the region stands economically out from the other areas in Belgium.

The economic activities in the relatively larger metropolitan areas of Flemish Diamond are distinct, with an emphasis on the industry in Antwerp, mainly because of its major port, from where a considerable amount of work and commercial activity is generated. At the same time Brussels, being the Belgian capital, is eminent for the concentration of the administration and its function for the European Community, as well for its employment potential. Leuven and Ghent are widely recognized as university towns and cultural hubs. As a result of such attractiveness, during the last decades, these cities have seen the transformation of arable and grassland to built-up areas with complex spatial structures which have different functions such as housing, recreation, and work (FPS Economy, SMEs, independent Professions & Energy, 2006).

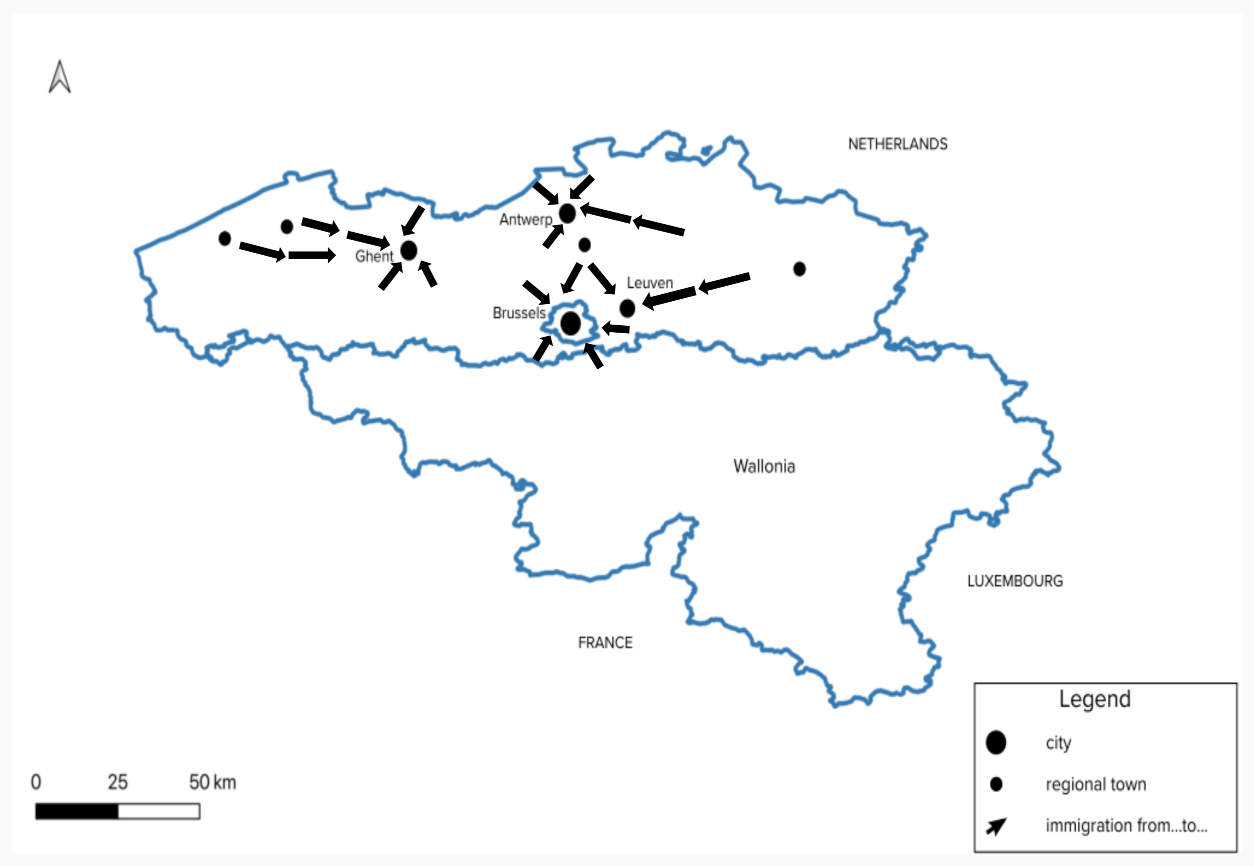


Source: Own elaboration

Figure 8. A map of the Flemish Diamond within Belgium

4.2.2 Migration and urban sprawl

Because of the strategic geographical location and economic development, Belgium, and especially Flanders, has recently faced accelerated migration. The most significant migration flows are seen from Eastern Europe when we refer to external migration. However, the most robust flows of migration are within the regions of Belgium and particularly within the provinces of Flanders. (Loris & Pisman, 2017) claim that the internal migration is four times as strong as the external migration illustrated in Figure 8 where the flows to and from major cities and regional towns are depicted. Furthermore, it is argued that these internal migration flows are driven by suburbanization processes. The most prominent is the suburbanization of the Brussels Capital Region towards Flanders. This is a phenomenon mainly generated from young families and young adults who migrate to major cities for employment or education (Kakaš & Gruber, 2016).



Source: Own elaboration adopted from (Loris & Pisman, 2017)

Figure 9. Migration patterns in Flanders based on internal migration figures from 2015

Nevertheless, the public sector of Flanders is tailoring new policy plans to deal with the ongoing urban sprawl due to migration patterns within the region (Ruimte Vlaanderen, 2017). Considering such occurrences, this study attempts to reveal the differences in activity-travel patterns caused by the migration of the Flanders population from rural to urban zones.

4.3 Application of FEATHERS in the case-study

Considering that the FEATHERS framework was initially devised to facilitate the development of activity-based microsimulation models for transportation demand in Flanders (Janssens et al., 2010), this section aims to bring to attention various strategies and policy scenarios applied and analysed in the study area with the help of the framework. Checking for the existence of such policy scenarios and their derived impacts at the level of Flanders can help to further understand to what extent the activity-based model is validated.

A fuel cost scenario was considered by (Kochan et al., 2007). The increase in the variable of fuel cost for all times of the day and for a fraction of the Flemish population led to changes in the travel demand. Specifically, FEATHERS predicted a decrease in the average number of car trips and the VKT/ travel distance. Such results appear to make the model a promising tool indicates (Kochan et al., 2007). In line with this, (Pirdavani et al., 2012) went further to investigate the road safety implications of the scenario. The study revealed a substantial benefit and a reduction of 2,8% on the number of injury crashes if the fuel price is increased by 20% in Flanders.

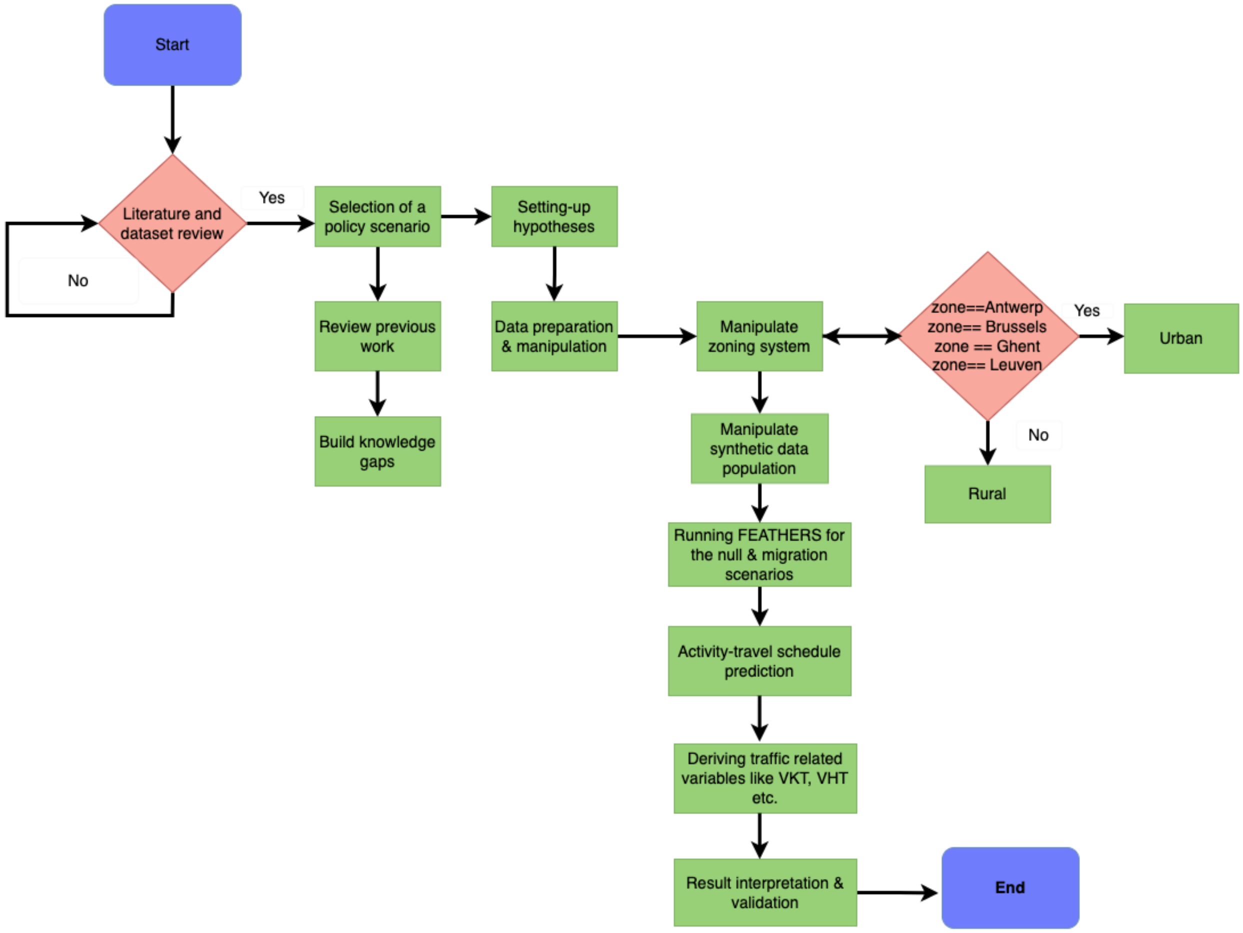
To further test the sensitivity of the FEATHERS scheduling model, (Kochan et al., 2011) studied the effects of teleworking on the total distance traveled in Flanders. It was reported that in 2002 the total distance traveled decreased by 1.6% while the proportion of teleworkers that telework on a working day was 3.8%. Since the cause-effect relationship between teleworking and a reduction in VKT is reasonable and in line with the findings in the literature, it can be concluded that the model performed well. In addition, (Pirdavani et al., 2014) evaluated the traffic safety impacts of conducting a teleworking scenario (5% of the working population engages in teleworking), having Flanders as a case study. The results imply that because there is a reduction in VKT, there is a considerable benefit in traffic safety and a reduction in the number of crashes.

Moving forward to demonstrate other applications in the study area, the prototype model (the integration of FEATHERS with MATSIM) demonstrates a few policy scenarios in the city of Hasselt, Limburg province. Restricting car access and increasing the bus frequency were two scenarios that were examined by (Adnan et al., 2020). After simulations were performed, the results revealed that restricting cars in the Hasselt inner ring shifts car drivers/passengers to change their mode of travel and the location of their activities. Whereas the increment in the frequency of public transport, specifically buses, caused a shifting of bike users towards public transport, which is an undesirable result of the policy if the objective is to improve sustainability and the environment. According to (Adnan et al., 2020), these results largely agree with the results reported in other similar studies, which validate the framework of FEATHERS once more.

5 Methodology and Scenario development

Figure 9 presents the methodological framework employed to carry out the research needed to achieve an effective outcome for this master thesis. As a first step, extensive research was performed based on previous research work conducted with various activity-based models and FEATHERS, so as to determine the most suitable and emerging policy scenario that could be assessed. Nevertheless, the choice of the scenario for the purpose of the thesis was somewhat limited. The dataset provided from IMOB (Transport Research Institute) was lacking meaningful attributes and therefore was a need to adapt to the given input. Hence, the process of deciding about the scenario was an iterative process until it was firmly agreed that the migration scenario could be run successfully, taking into consideration the given dataset and the model of FEATHERS.

More methodological aspects of setting-up hypotheses and other crucial steps for being able to execute the migration scenario within FEATHERS model can be found in the sections below. The output derived from the ABM is analyzed separately under Chapter 6.



Source: Own elaboration

Figure 10. Research methodology flow chart

5.1 Setting-up hypotheses

In order to evaluate the impact of the policy scenario on activity and travel demand in Flanders, a null (current situation) and three migration scenarios (hypothetically - based) are executed through a simulation-based analysis. To this end, an activity-based model in the FEATHERS (Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS) framework is applied to the Flemish population to derive in-depth information on Flemish individuals' activity-travel behavior and travel demand.

1. *A null scenario*

A null/base scenario is executed for the entire population of Flanders (*N*=6294755) allocated in different TAZs within FEATHERS. The model predicts their activity and travel behavior on a daily basis.

2. *Migration scenario*

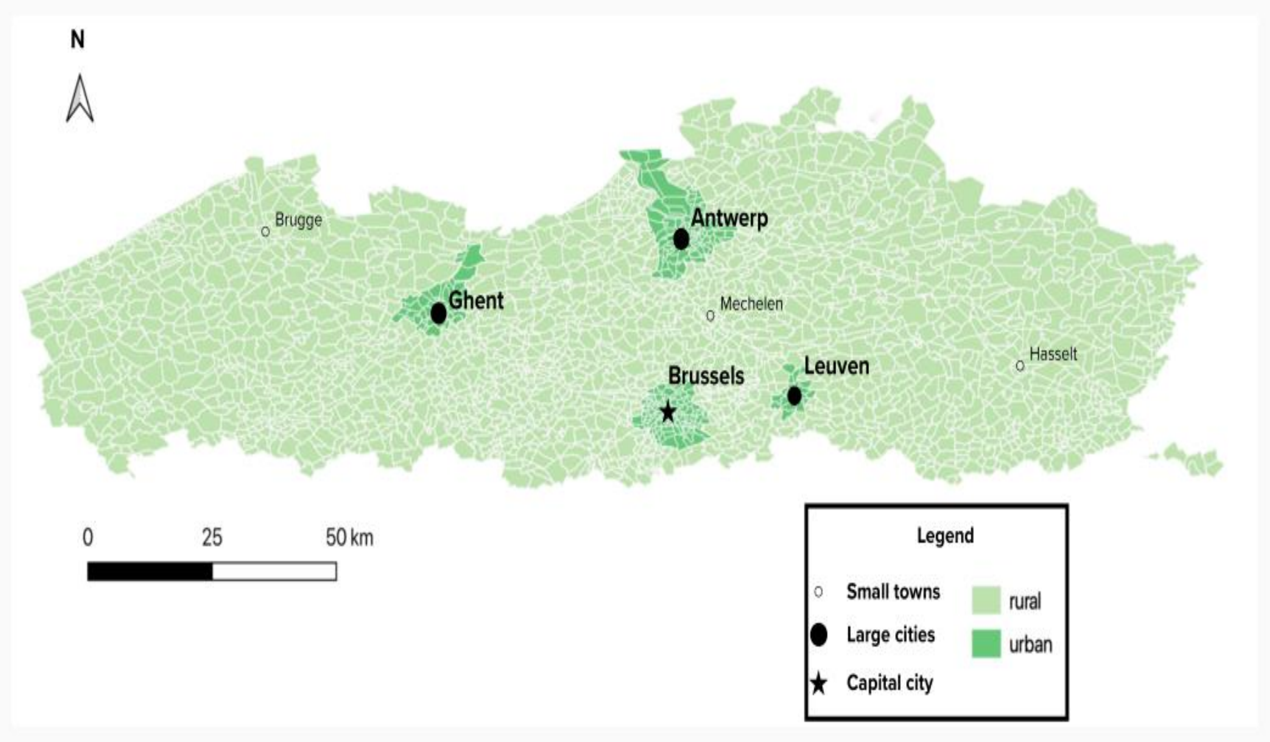
Taking into consideration the advantage of activity-based models to predict a change in the activity and travel demand when a TDM is imposed, this study assumes to randomly migrate the population of Flanders from rural to urban zones. The interzonal migration is performed on different fractions, therefore, the procedure is replicated. Specifically, as below:

- 2% of the total Flanders population (*n*=125895) with equal proportions
- 5% of the total Flanders population (*n*=314738) with equal proportions
- 10% of the total Flanders population (*n*=629476) with equal proportions

As a result of the spatial redistribution of the Flanders 'individuals, the synthetic population is modified for each scenario. The new synthetic population reflects the fraction of the population allocated to the new TAZs entitled as urban zones. The following section describes the procedure of defining the urbanization degree within the FEATHERS zoning system.

5.2 Data preparation

Following the need for migration analysis as described in Chapter 4, it was essential to prepare the FEATHERS zoning system dataset in order to align with the purpose of the research. The first step was to organize the TAZs following the urban/rural division based on the urbanization degree of each zone. Considering that the Flemish Diamond is regarded as the most urbanized area of Flanders with an increased population density and economic development concentration, TAZs belonging to that area were assigned as urban. In contrast, the rest of the spatial units were considered rural. Having this classification in mind, the next step was to align the space resolution of FEATHERS with that of OpenStreetMap (OSM). Since the model resolves space in TAZs, a municipality in FEATHERS may contain more than one zone (city), and a city have more than one TAZ (Bao, 2016). This means that our selected study areas incorporate more than one TAZs, as shown in Figure 10. To be able to edit, prepare and manipulate the zoning dataset, QGIS (Quantum Geographic Information System) software was used. Additional open data resources such as OpenStreetMap have enabled geospatial data regarding the administrative boundaries of Flanders. The OSM datasets were used to feed the FEATHERS zoning system with information on the administrative boundaries of the cities of the Flemish Diamond. After the data processing procedure, the Flanders region was categorized into rural and urban TAZs, as shown in the figure below.



Source: Own elaboration

Figure 11. Rural and urban division of Flanders in FEATHERS zoning system

After assigning the urbanization degree to the zoning system, the individuals of Flanders are randomly allocated to different TAZs with respect to the migration scenario. This is achieved using Pandas, an open-source Python package mainly used for data analysis and manipulation. For each scenario, a specific code was written. A sample of the code written to achieve the desired change in the population of Flanders for the migration scenario where 5% of the population is relocated to urban zones, is described in detail in Appendix I.

5.3 Running FEATHERS

The null and migration scenarios were run in the model of FEATHERS at different timestamps. The computation time of the model is moderately high. For a single model run, more than 24 hours are needed (using the total population) to execute the scenario. The resulting model results are given in the form of predicted schedules for groups of individuals living in a particular area. The model can also predict individuals’ activities during the day in-between their regular trips. In other words, for each trip and location, FEATHERS knows what activity individuals are involved in, at a particular place, at a specific moment in time, and for how long. As a user of FEATHERS, a multitude of answers in response to the policy scenarios are achieved. More information about the results obtained and the analysis behind them is discussed in Chapter 6.

6 Results and Analysis

6.1 Selection of influential variables

Despite the growing interest in considering key social influence variables such as attitudes, habits, awareness, etc. in transport models (Di Commo, 2014), this research is limited to taking into account and analyzing classical socio-economic and demographic characteristics (i.e., age, gender, household composition, household number of cars, etc.) and the context (i.e., trip purpose and activity type). To understand the travel behavior impacts of the migration policy scenario, it is interesting to look at the changes in the travel-related attributes playing a role in the whole chain due to the migration scenario. These attributes are as below:

- *Number of Trips*

The total number of trips is a significant indicator when analyzing transport demand. If it is correlated with socio-demographic characteristics, activity type, and/or travel mode, meaningful information can be extracted from it. Typically, it is analyzed alongside travel mode to reveal changes in mode share. At the same time, the indications become more important when the total number of trips is scrutinized with respect to the time of the day, such as morning peak and/or evening peak hour. During these periods, the number of trips is usually denser.

- *Travel Mode*

Useful information on the impact of a policy scenario can be drawn out when the travel mode is analyzed with activity type. It is beneficial to get a clear overview of the leading travel mode for a particular activity and whether there is a fluctuation in the usage of a specific transport mode after implementing a policy.

- *Vehicle Kilometers Travelled (VKT)*

VKT represents the travel distance from the origin to the destination. It is one of the most researched and analyzed variables in travel demand modelling. Variations in the total number of vehicle kilometers travelled indicate the success or failure of a specific policy or travel demand measure. This variable is mainly analyzed with the activity type, which will also be the case for this research.

- *Vehicle Hour Travelled (VHT)*

It constitutes the total amount of the travel time, known also as trip duration. Same as vehicle kilometers travelled, VHT is a crucial variable in forecasting travel demand. Therefore, this attribute is examined alongside activity type as well.

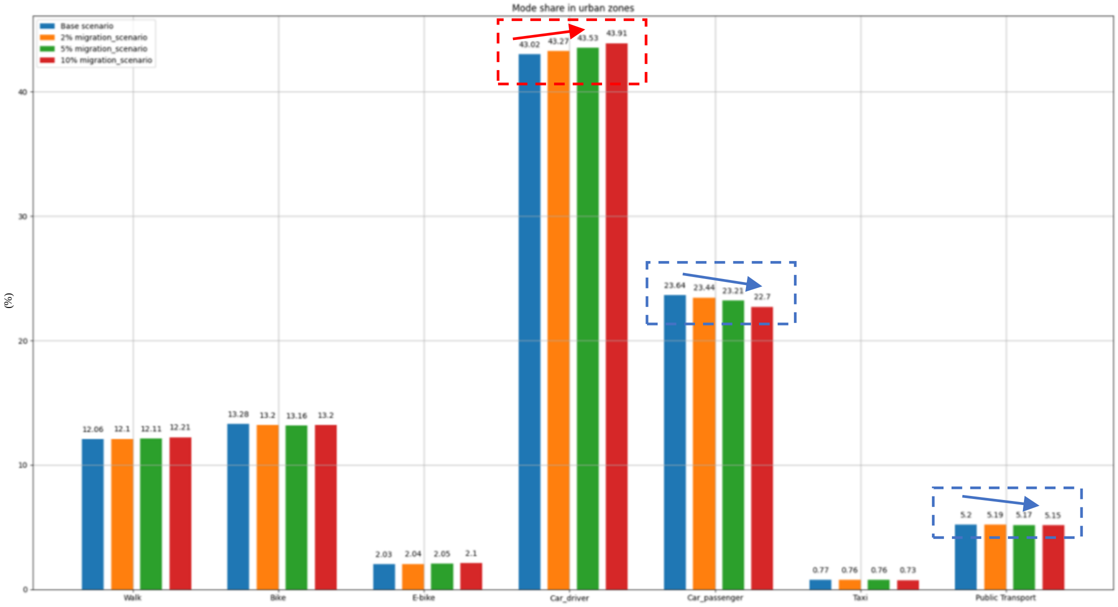
6.2 Policy scenario analysis

6.2.1 Mode shares

- *Morning peak hour*

The results in Figure 12 indicate that in urban zones during morning peak hours (considered between 08:00 AM- 10:00 AM for Flanders), the most notable effects are seen in car as a main travel mode. There is on the one hand, an increase in the total number of trips conducted by car as a driver (0,89% points), and on the other hand, a decrease in the number of trips by car as a passenger (0,94% points). Because of the migration scenario, there is also a slight increase in the number of trips/morning peak hour done by walk (0.15% points) and e-bike (0.07% points). Also, there is a decreasing trend in the number of trips conducted by bike, taxi and PT after the scenarios.

In absolute terms, car as driver trips increase from 465,162 to 599,939 trips/morning peak hour (i.e., an increase of 134,777 trips), whilst car as passenger trips decrease with 54,469 trips/morning peak hour. Concurrently, the total number of trips by walk and e-bike increase after the implementation of the 10% migration scenario with 36,410 trips/morning peak hour and 6775 trips/morning peak hour respectively. However, this is at a cost of a decrease of public transport trips from 70,370 to 56,195. In general, as more Flemish population is relocated to urban areas, the higher is the dependency in private cars (as a driver) to commute. Having a high population density might not guarantee that more people will use PT (World Bank, 2015). The major reason could be that the public transport is not considered an attractive mode in urban areas due to accessibility, walkability (having to walk a big distance to reach PT), frequency etc. It is rather preferred to walk or e-bike instead of taking the bus.



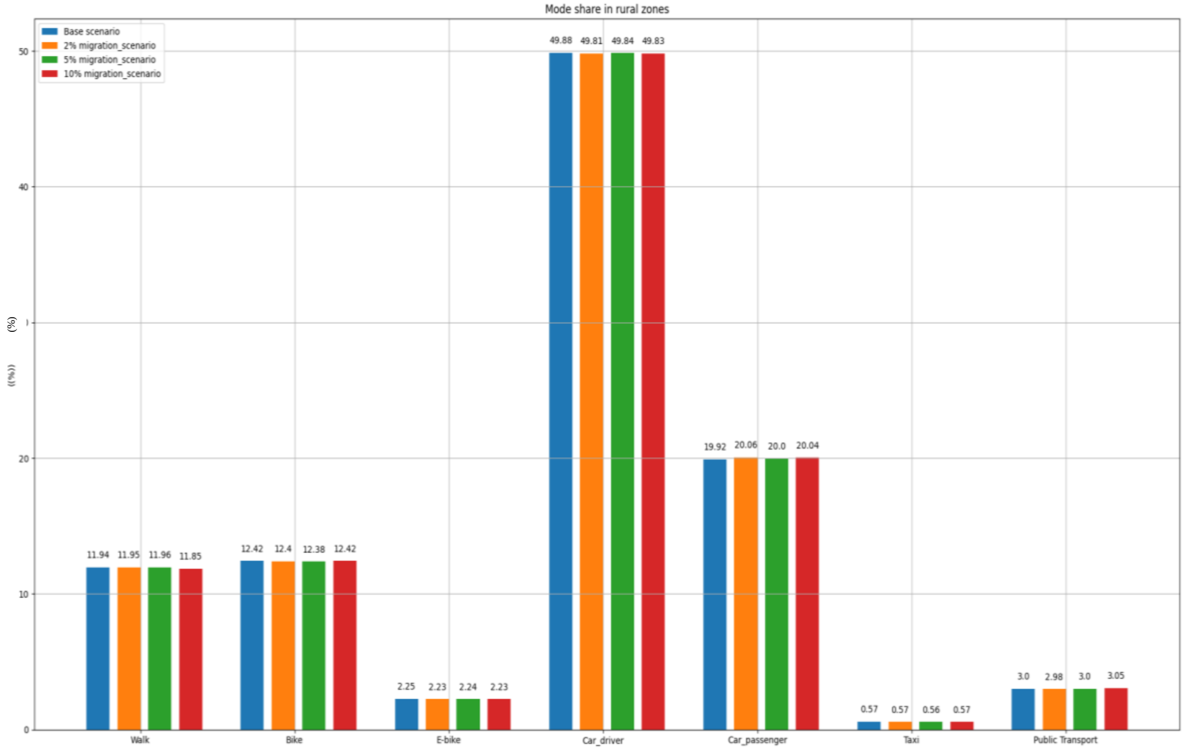
Source: Own elaboration

Figure 12. Mode shares in urban zones during the morning peak

Shifting our analysis at rural zones, it can be seen from Figure 13 that the differences between base and migration scenarios are less prominent compared to urban zones. The results indicate that during morning peak hours in rural zones, there is a decrease in the total number of trips from 2,748,293 to 2,465,566 (i.e., a reduction of 282,727 trips), which is in line with what one could expect after relocating 10% of the Flemish population in urban zones.

Nevertheless, there is a shift toward modes as car passenger and PT, which can be seen by the slight increase in the total number of trips from 19,92% to 20,04% and from 3 % to 3,05%, respectively. Not by surprise, there is a tiny decrease in the total number of trips by car as a driver (0,05% points) and by walk (0,09% points). In addition, there is no significant effect on other travel modes such as bike, e-bike and taxi.

It is crucial to note that the reason why there is no consistency between migration scenarios especially in rural zones, is because of the simulation error that activity-based models incorporate after certain simulation runs (Petrik et al., 2020). The microsimulation process within the FEATHERS model is stochastic so mode share distribution is basically random among scenarios. The uncertainty of the results depends on how frequently the alternative is predicted in the choice process. In other words, because the frequency of the car as a driver is higher than other modes, there is less stochasticity compared to other modes.



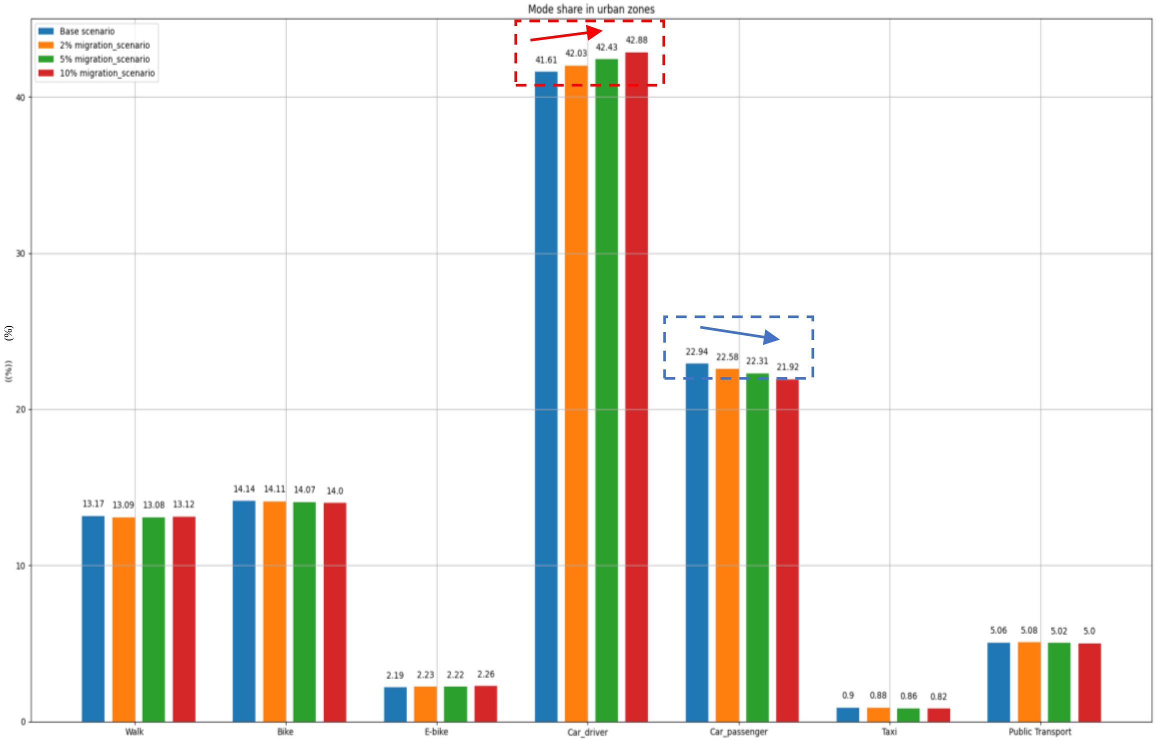
Source: Own elaboration

Figure 13. Mode shares in rural zones during the morning peak

- *Evening peak hour*

The results obtained for the urban zones during the evening peak hour (considered between 4:00 PM -6:00 PM, in Flanders) relatively replicate the trends seen in the morning peak hour. In absolute terms, there is an increase in the total number of trips performed in urban zones from 2,040,737 to 2,626,808 (i.e., an increase with 586,071 trips/evening peak hour) after the implementation of the 10% migration scenario. The highest differences between scenarios are again seen on car as the main mode of the trip as illustrated in Figure 14. There is an increase by 1,27% points (or with 277,146 trips/evening peak hour) made as car driver which is at the cost of a decrease of trips made from other modes as for instance; by 1,02% points as car passenger, by 0,14% points as a bike traveller by 0,05% points as walking etc.

Nevertheless, considering that the total number of trips in urban zones considerably increases after the 10% migration scenario, each of the modes experience an increase in the total number of their trips during evening peak hours, but their share against other modes does not necessarily increases. For example, although the total number of trips by PT increases from 103,192 to 131,415 (i.e., an increase with 28,223 trips/evening peak hour) there is a decrease by 0,06 % points on PT trips. This is because public transport losses share against other modes.

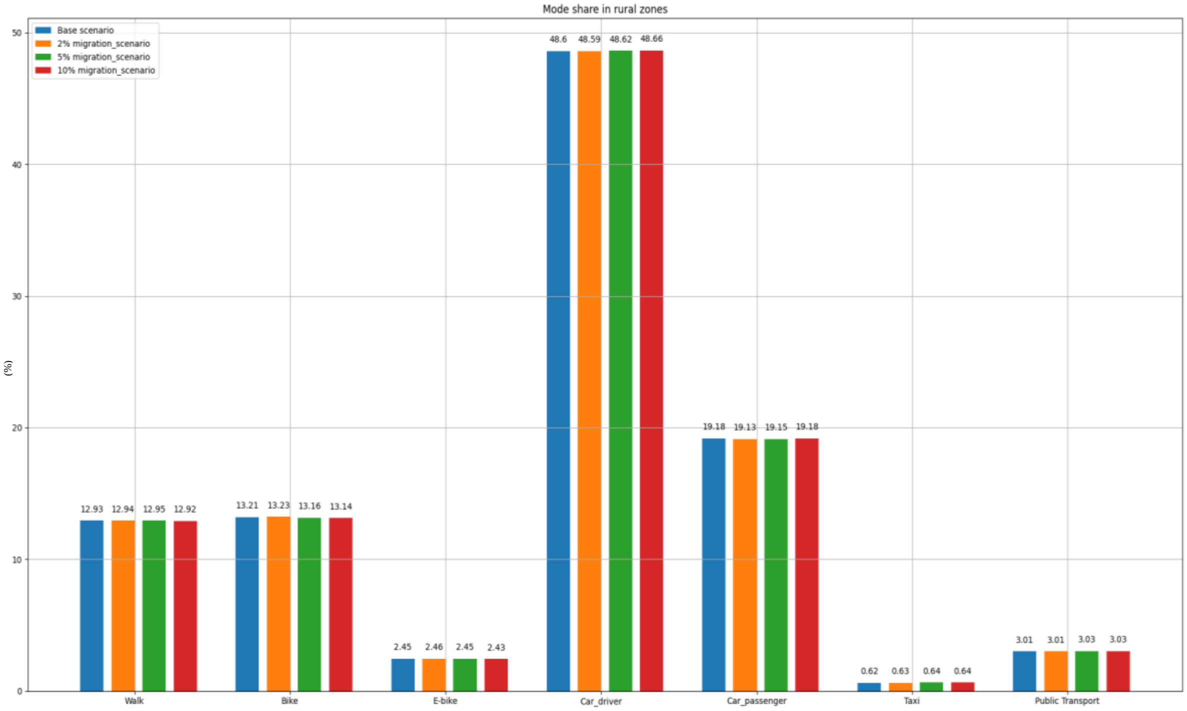


Source: Own elaboration

Figure 14. Mode shares in urban zones during the evening peak

As we move further on the analysis of the output obtained for rural zones, Figure 15 indicates different results compared to those obtained for the mode shares during the morning peak. Surprisingly, there is a slight increase by 0,06% points in the number of trips made by car as a driver although 10% of the population has been migrated to urban zones. One could have expected a decrement instead as seen on the case of the morning peak. In addition, during the evening peak hour there is no significant difference on the mode share for other travel modes such as walk, bike, e-bike, car passenger, taxi, and PT.

In absolute terms, there is a decrease on the overall number of trips after the implementation of the 10% migration scenario from 5,186,010 to 4,595,950 (a decrease with 590,060 trips/evening peak hour). Nevertheless, there is no significant impact on mode share as Flemish individuals apparently seem to stick to their previous travel mode.

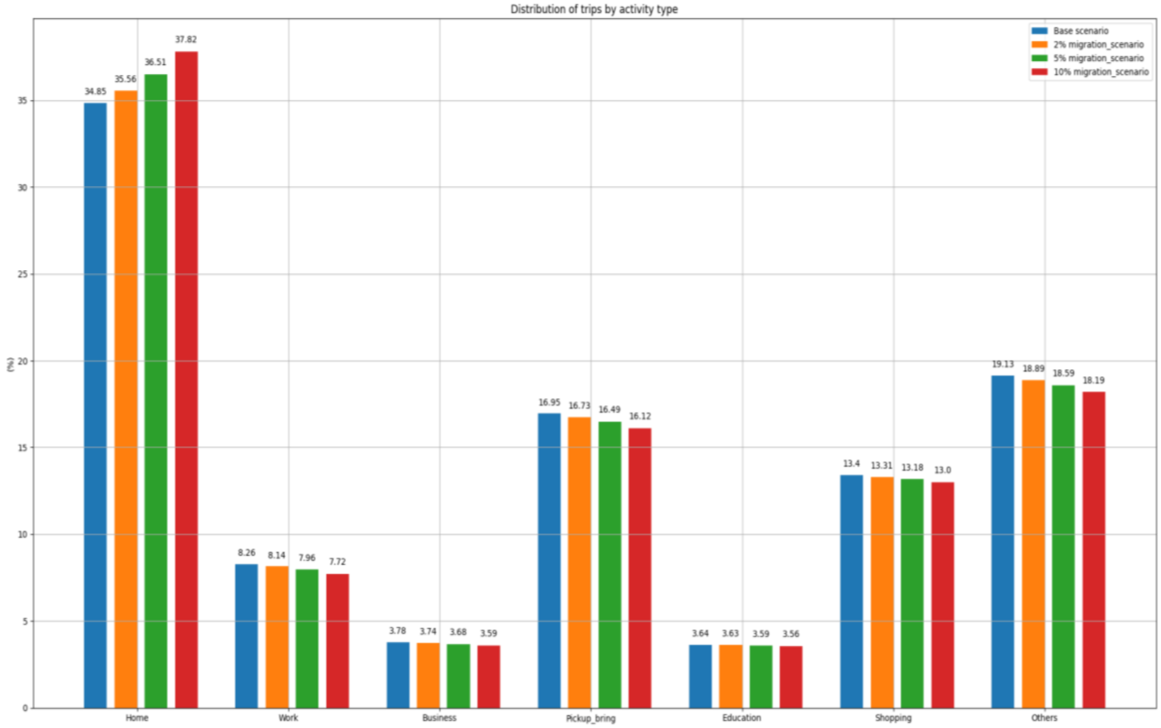


Source: Own elaboration

Figure 15. Mode shares in rural zones during the evening peak

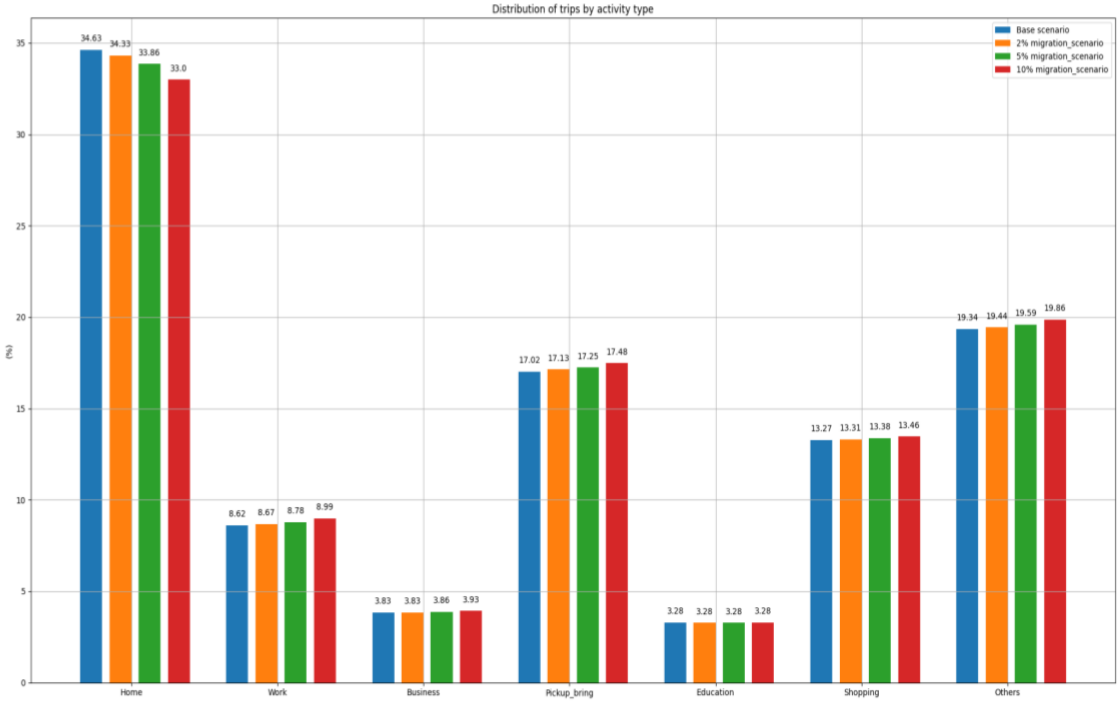
6.2.2 Trip frequency per activity type

Since individuals travel because of the need to conduct an activity, it is of paramount importance to scrutinize the relationship between trip frequency and activity type after the relocation of Flemish individuals in urban zones. The results obtained indicate different impacts on both zones as Figures 16 and 17 illustrate. There is a considerable increase in home-based activities (by 2,97%) in urban zones, whereas all other activities incur a decrease in the trip frequency. Contrastingly, the rural zones experience a reduction in home-based activities (by 1,63%) and an increase in the number of trips for other activities with a peak for pick-up and bring activities (by 0,46 percentage points) and work activities (by 0,37 percentage points). It goes without saying that the result obtained on the activity choice after the execution of the scenarios do not provide cogent ground for relying into. In urban areas, because of the dense concentrations of people (especially after relocating 10% of the rural population there), employment, and shopping facilities, we expect to have a higher frequency of trips for such activities. While on the contrary, the dispersed nature of rural opportunities and activities should be reflected in less discretionary trip frequencies. However, our results indicate the opposite of what one could have expected to happen taking into consideration the urbanization degree of the zones and the policy scenario tested in the activity-based model.



Source: Own elaboration

Figure 16. Distribution of trips by activity purpose in urban zones



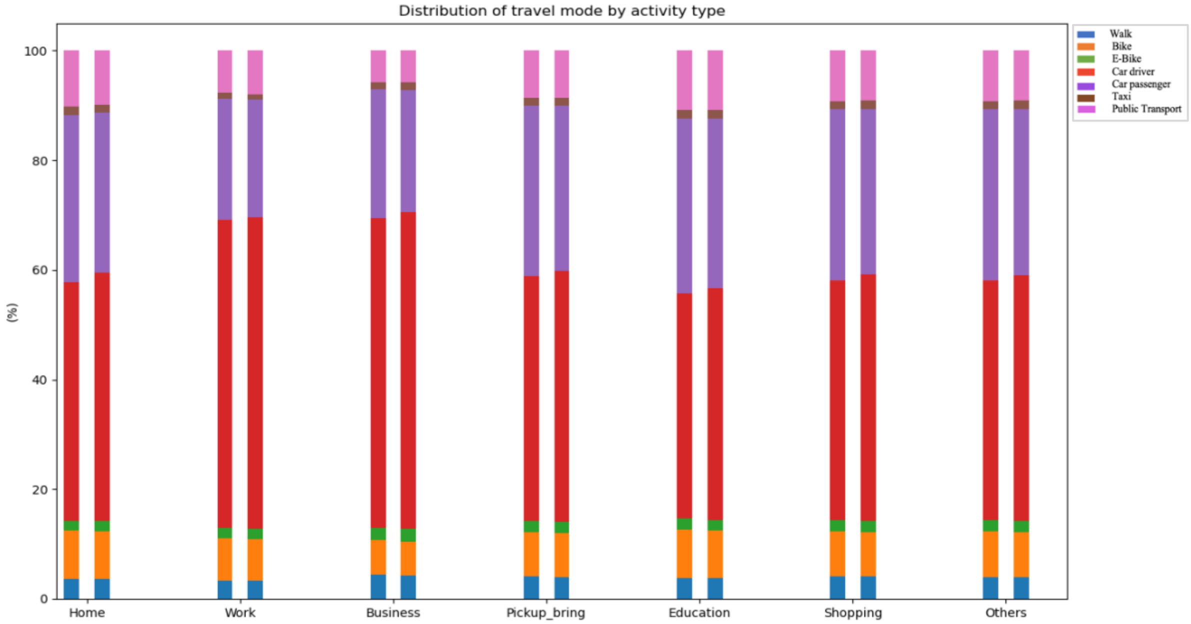
Source: Own elaboration

Figure 17. Distribution of trips by activity purpose in rural zones

6.2.3 Mode shares per activity type

Considering that this thesis is analysing various scenarios, it should be emphasized that it is challenging to depict them together in the same graph. Therefore, the figures below are restricted in portraying the results obtained from the FEATHERS simulation of only the base and 10% migration scenario for ease of comprehension. Furthermore, the choice was made with the aim to offer a more notable difference between the scenarios since the 10% migration scenario relocates to urban areas a higher proportion of the population. As it can be seen in Figure 18 and 19, the main travel mode for all activity types is car as a driver and car as a passenger in both urban and rural zones. The third most frequent mode is bicycle and since we are analysing the population of the Flemish region is entirely reasonable, as cycling is well rooted in their culture. Another important portion of mode share per activity purpose is taken by public transport, however, it is less significant compared to car as a vehicle.

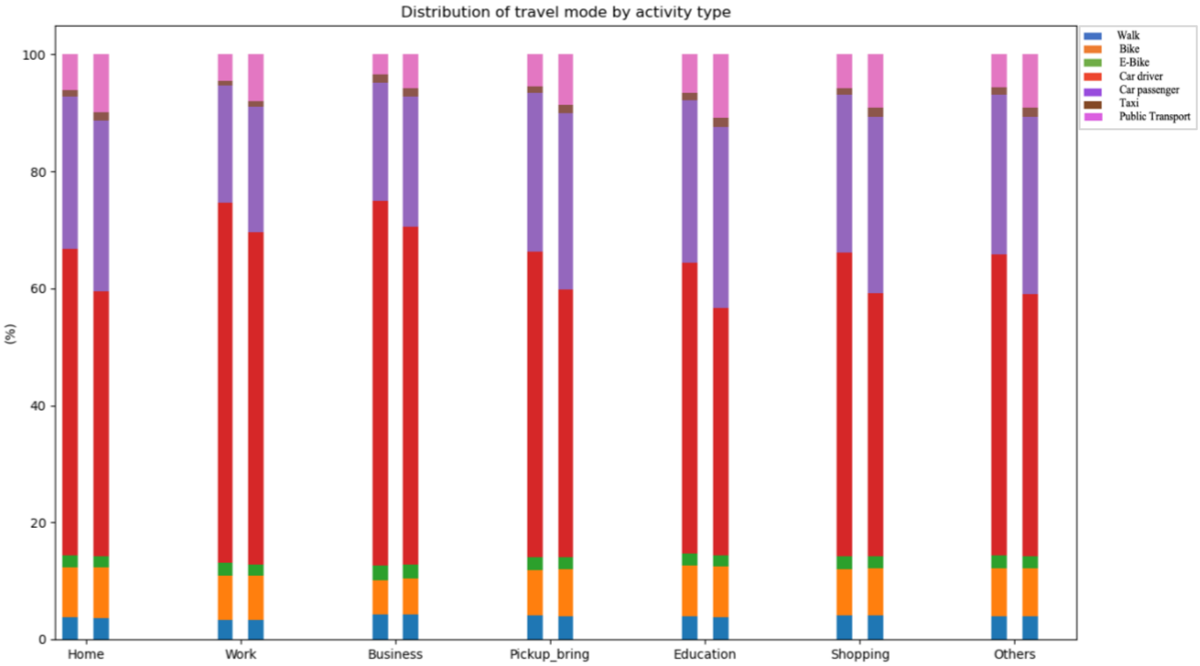
As we tend to make a comparison between activities, the results indicate an increase in the total number of trips made by car as a driver in urban zones mainly for home-based activities (1,81 %), shopping activities (1,22%) and business activities (1,21%) which is at the cost of a reduction on the total number of trips made from other modes. The most evident reduction is seen in the total number of trips made by car as a passenger for almost every activity (i.e., 1,3% for home-based activities, 1,05% for business activities etc.).



Source: Own elaboration

Figure 18. Distribution of travel mode by activity purpose in urban zones (base and 10% migration scenario)

The opposite takes place in rural zones after the implementation of the 10% migration scenario, where the total number of trips from car as a driver is remarkably reduced for all activities with a peak reduction for shopping activities (6,99 %). Here, it is at the cost of an increase in the total number of trips made for shopping activities by PT (3,45%) and by car as a passenger (3,31 %). As it can be clearly understood, the scenario has a contrasting effect on urban and rural zones. What makes the analysis rational is the fact that the results of the distribution of travel mode by activity type are plausible against prior results obtained on mode shares for both zones.



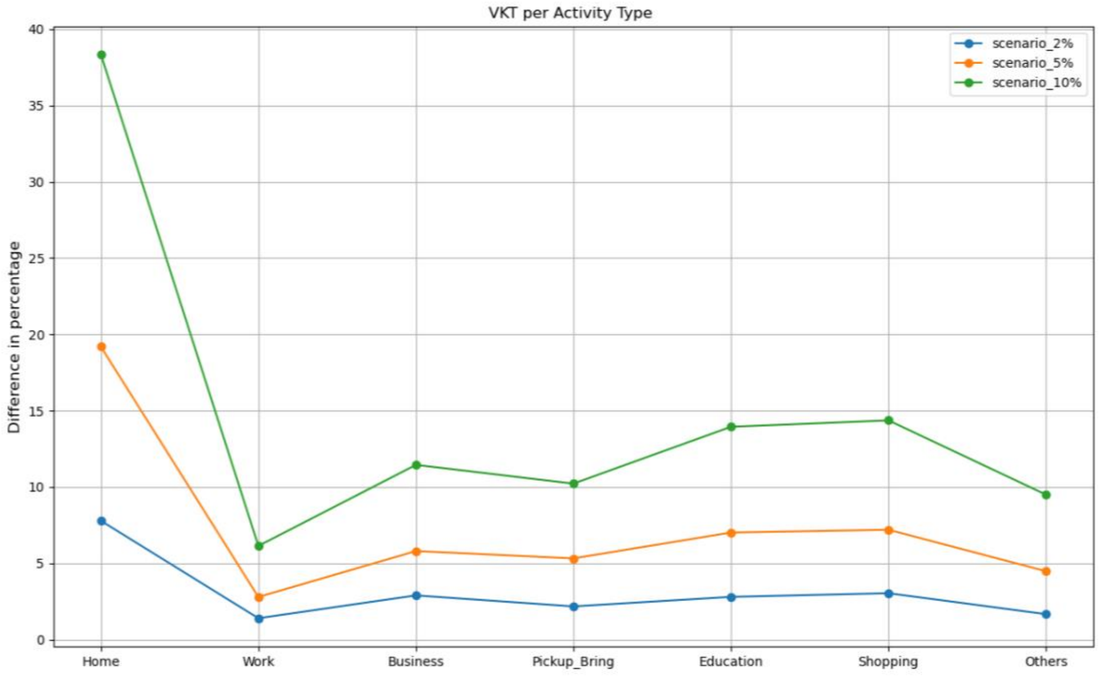
Source: Own elaboration

Figure 19. Distribution of travel mode by activity purpose in rural zones (base and 10% migration scenario

6.2.4 VKT per activity type

When analyzing vehicle kilometers travelled per activity type it was deemed that there is a noticeable increase on the vehicle kilometers travelled for each of the activities conducted in urban zones whereas, there is the opposite in the rural zones. The greatest alterations are found for home - based activities followed by shopping and education activities in both zones and for each migration scenario as figures below show. On the one hand, the urban zones experience a considerable increase by 38,34% in home-based activities, by 14,36% in shopping activities and by 13,94% in education activities after the implementation of the 10% migration scenario. On the other hand, the rural zones show a decrease by 14% in home-based activities, by 8% in education activities and by 6,2% in shopping activities for the same migration scenario of 10%.

In absolute terms, the total VKT increased from 49,348,597 km to 60,453,416 km (i.e., an increase of 11,104,819 km) in urban zones. Rural zones, in contrast experience a reduction from 161,749,916 km to 147,224,621 km (i.e., a decrease with 14,525,295 vehicle km travelled) after the execution of the scenario where 10% of the population is relocated to urban zones. These results show consistency with the results obtained for the number of trips during the time of the day (AM or PM peak) in the subsections above, which indicated an increment in urban zones and the inverse in rural zones. The higher is the distribution of trips per travel mode, more vehicle kilometres are expected to be travelled by each mode, and vice versa.



Source: Own elaboration

Figure 20. Differences in percentage with respect to base scenario in urban zones

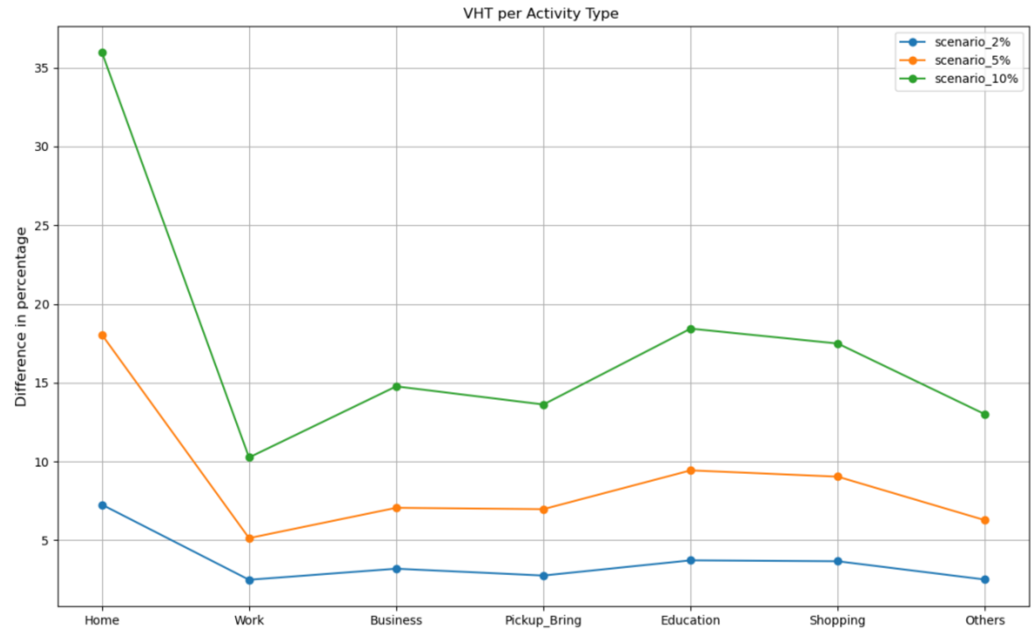
Source: Own elaboration

Figure 21. Differences in percentage with respect to base scenario in rural zones

6.2.5 VHT per Activity Type

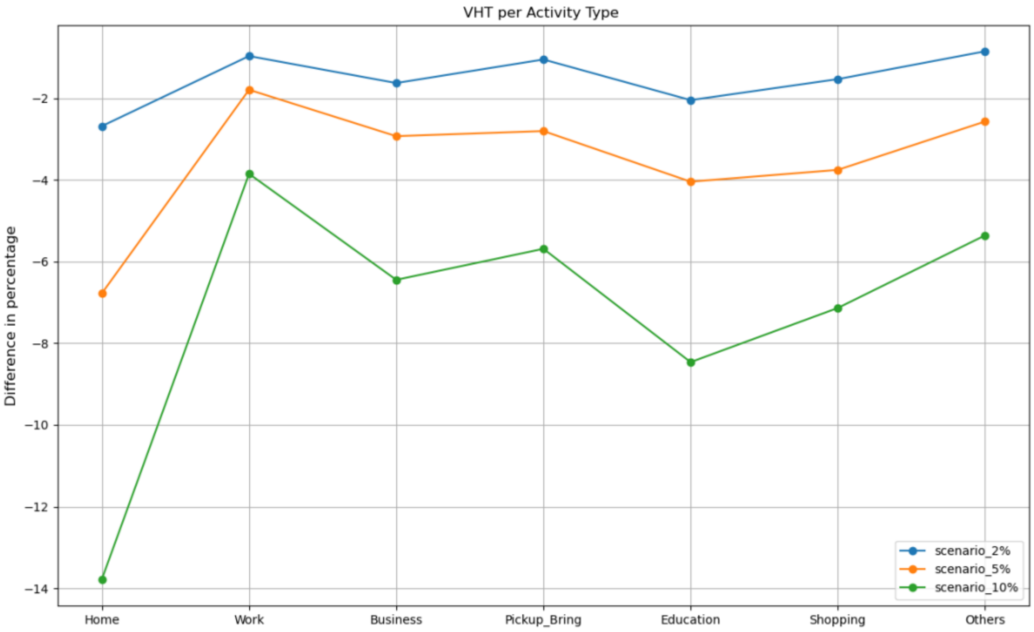
Following the changes revealed in mode share and total vehicle kilometers travelled there was a need to analyze vehicle hour travel as the main traffic attribute to check the impact after the implementation of the scenarios. As the total VKT continues to grow for each activity and scenario in urban zones, one could expect similar for the total VHT without checking the results. And, not by surprise, there is actually an increment in the total vehicle hour travelled in urban zones in respect to the base scenario as the results displayed in Figure 22 demonstrate. The highest increment in the total VHT is deemed to be for home-based activities by 35,98% (i.e., an increase with 66,786 hours travelled in a day unit), followed by education and shopping activities by 18,44% and 17.49% respectively. In total, there is a growth with 185,620 hours travelled/day in the urban zones after the execution of the 10% migration scenario.

Contrastingly, the total vehicle kilometers travelled in rural zones experience a diminution, where the time spent for home-based, education and shopping activities gets reduced after the 10% migration scenario by 13,77%, 8,46% and 7,13% respectively. Each activity experiences a reduction on the total VHT after the implementation of the migration scenarios with a peak reduction on the 10% one, with 202,748 hours travelled/day in total. This comes as a result of the reduction of the total VKT, and the number of trips observed above.



Source: Own elaboration

Figure 22. Differences in percentage with respect to base scenario in urban zones



Source: Own elaboration

Figure 23. Differences in percentage with respect to base scenario in rural zones

7 Concluding Thoughts

7.1 Discussion

The output generated from the simulation of the migration scenarios indicate several interesting findings that are absolutely food for thought. Population growth in urban areas is found to have notable impacts on activity and travel behavior for individuals living both in urban and rural zones. The policy scenario affects almost all the attributes taken under investigation. There is a prominent mode shift from car as a passenger and public transport to car as a driver during peak hours in urban zones, which eventually lead to an increase in the total number of trips since more trips are now done individually. In contrast, rural zones experience a totally different modal shift after the implementation of the migration scenarios, with an increment in the number of trips made by car as a passenger and public transportation.

Negative relationships between the number of trips, car as a passenger and PT after the relocation of individuals in different proportions to urban zones do not seem to be plausible with what one would expect to happen. Generally, people instinctively try to adapt to the new conditions where they are at. Hence, because of the efficacy of urban transport systems in urban areas where the PT is more readily available, accessible and infrastructure is geographically closer than in rural areas (Liftango, 2020) the intuition leads to the fact that more trips should take place through public transport services. Furthermore, urban areas typically have significant walkability scores as individuals tend to walk for doing their activities (Berry et al., 2017), which is not the case in the output generated from FEATHERS. Also, in rural zones because individuals travel greater distances to reach their key service locations and have higher dependency on car ownership compared to their urban counterparts, it was expected to see an increment in the usage of private vehicles. Nevertheless, the results obtained for each of the migration scenarios indicate the opposite, where a slight increase is found on PT and taxi as main modes of travel.

Shifting our discussion to an activity behaviour view, the findings reveal an impact on the activity choice in both zones. Urban zones experience a decline in trip frequency for activities that are not expected to happen. Same phenomenon happens for rural zones, where the number of trips increases remarkably for certain activities after the execution of the migration scenarios, even though a considerable number of individuals were relocated to urban zones. As already highlighted, the results are not trustworthy but encouraging enough to perform future research.

On the other hand, it was interesting to find that the main travel mode for all types of activities (education, shopping etc.), despite the urbanization degree in Flanders, is car as a driver. It reassures one more the high dependency the individuals of the Flemish region have on cars for conducting their activities. However, there is an increasing trend of car (as a driver) usage for doing their activities in urban zones contrastingly to what happens in rural zones. Here, as previously found and discussed in mode share analysis, is a shift towards using car as a passenger, public transport and walking for doing the activities in rural zones after simulating the scenarios. Although the results leave ample room for uncertainty and discussion as they stand against previous research done in the transportation field, they are much in line with the statistics obtained for mode shares in both zones. Therefore, the results can be justified from the fact that FEATHERS framework has a certain simulation uncertainty as (Adnan, 2020) explains, where the magnitude of all kinds of uncertainty strongly depends on how frequently the alternative is predicted in the choice process. For instance, mode share percentage uncertainty is estimated to lie within the range of 0,04% for car traffic. In other words, the mean mode share percentage can be subject to a standard deviation of 0,04%. Therefore, since the differences observed between scenarios are mainly in the range of 1-2 %, it is crucial to consider this magnitude of uncertainty when interpreting the impacts of the migration scenarios.

As we move along with our constructive discussion, it is essential to focus on the impact of the migration scenarios on the vehicle kilometres and vehicle hours travelled. It was undoubtedly critical to find out the correlation between these two attributes and the number of trips. Practically, it is revealed that the less travel there is, the lower the VKT, the lower the VHT and vice versa. Hence, the positive impact of the migration scenario on the vehicle kilometers travelled in rural zones is attributed to the reduction of the total number of trips as a considerable number of individuals relocated to urban zones. After the execution of the 10% migration scenario, the total VKT is reduced by 8,98% within the rural zones, which is meaningful, especially in mitigating greenhouse gas emissions and combating climate change. (Sims et al., 2014) emphasizes how challenging transport has been for reducing its significant fossil impacts energy use and associated carbon emissions since the 90s. However, such reduction is at the cost of an increase on the total VKT in urban zones.

Lastly, we also scrutinize the vehicle hours travelled – per being the only non-renewable resource - to measure the effect of the policy scenario. In transport planning, it"s not only necessary to estimate the vehicle kilometers traveled but the travel time as well. The decrease in the total VHT matches the downward trend seen in the total VKT in rural areas and the opposite in urban areas. In other words, because the vehicle kilometres travelled for a particular activity in a particular zone are reduced or increased, consequently, the vehicle hours travelled as well.

7.2 Conclusions

Many of the results from this research are indicative rather than conclusive. The major factor influencing the policy scenario output is the limited dataset and the model calibration. Considering the means provided, it has been possible to find substantial differences between scenarios, however through the interpretation of our results, it is recognized the need for further work. In general, the results do not align with the intuitive expectations one could have before running the scenarios and, most importantly with the findings in the literature, therefore more cross-validation needs to be done. A couple of peculiar results were found when analyzing activity and travel related attributes especially in terms of mode choice for both urban and rural zones, nevertheless it isn't easy to draw robust conclusions in this regard. In a nutshell, it was interesting to find that social and demographic trends such as migration from rural to urban zones may produce a structural shift in the relationship between places and time allocation of individuals invalidating existing activity and travel behavior.

7.3 Limitations and future research

There are some sources of uncertainty in the simulation framework, such as input data, the modelling structure, and calibration as (Adnan et al. 2020) indicate, and furthermore, the methodology followed to manipulate the FEATHERS subzone data to match the purpose of this research. The future work shall focus on further ameliorating the precision used for categorizing the Flanders region into urban and rural zones. A more detailed division based on the actual urbanization degree of each zone can expand and improve the categorization used by including other cities or municipalities of interest in Flanders region for individuals to migrate. This might derive a different impact on the activity and travel behavior patterns of the Flemish population. Furthermore, more effort shall be put into enriching the current population dataset. If more socio-demographic and economic information such as PT subscription, monthly income, etc. are provided, more detailed analyses can be performed regarding the impact of the migration scenarios. Last, but certainly not least, an integrated framework which offers the demand and supply side for testing the policy scenarios, would absolutely provide more credible and rational results and leave less room for ambiguity. This shall ultimately improve the quality of the research and provide more conclusive results.

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Appendix I

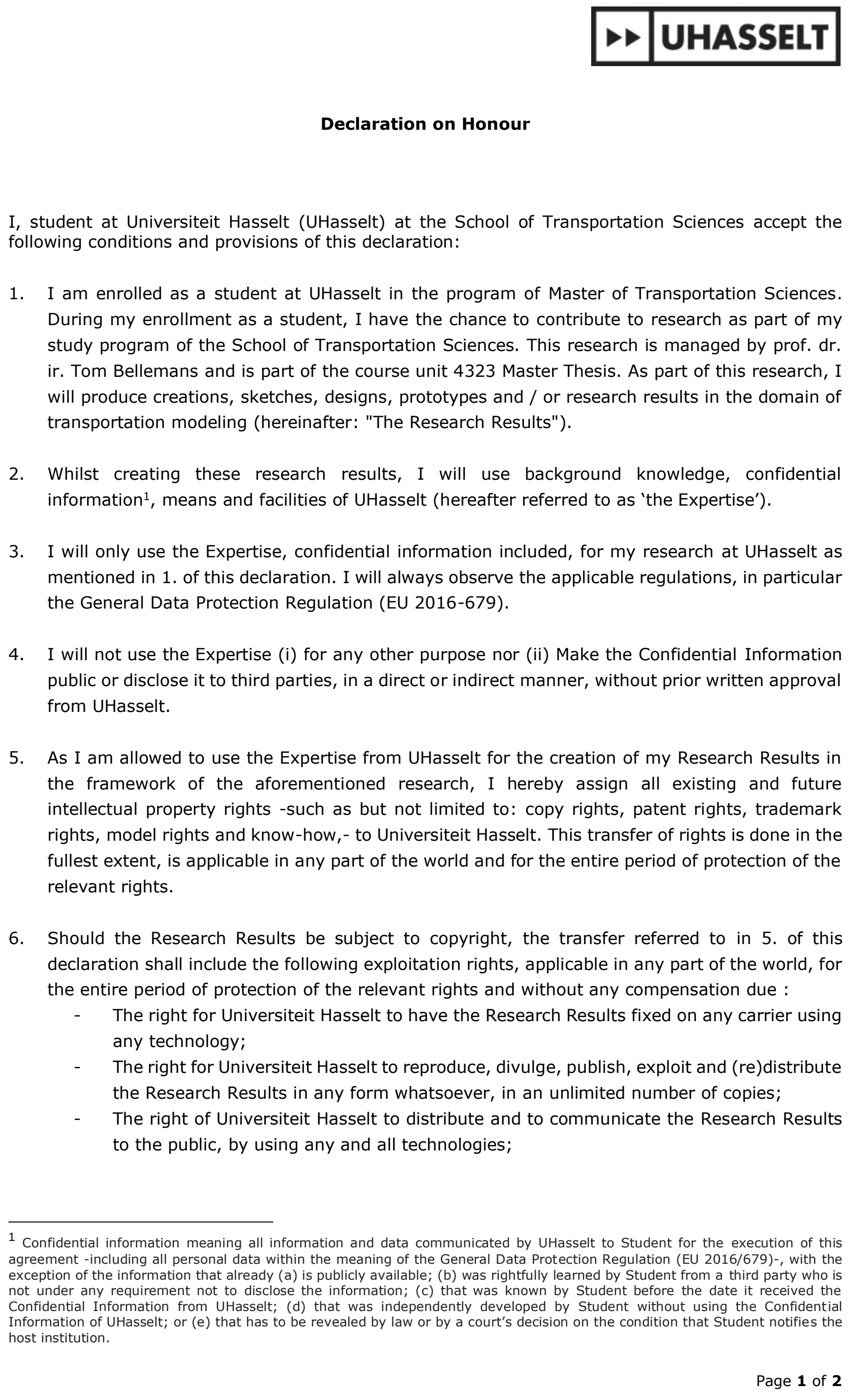
Python script for manipulating the synthetic data population file (5% migration scenario)

```
import pandas as pd
import csv
import random

#In [2]:
file_name=r"/Users/eridona/Feathers/Base scenario
05:06:22/Population_frac_1.csv"
df = pd.read_csv(file_name,engine='python')
print(df.columns)

#In [3]:
file_name=r"/Users/eridona/Feathers/Migration
scenario/new_subzones_urb_rural.csv"
df_1=pd.read_csv(file_name, engine='python')
print(df_1.columns)

#In [4]:
#Subzone_0 list (only those zones that are classified as "urban")
df_1.drop(['ID','URB','ARBTOT', 'LLSCH', 'DAG', 'NONDAG', 'HORECA','BANK',
'POP'],axis=1);

# In[7]:
df_urban=df_1[df_1['URB_DEG']=='urban']
zone_urban=df_urban["SUBZONE0"].tolist()
print(zone_urban)

# # In[9]:
df_rural=df_1[df_1['URB_DEG']=='rural']
zone_rural=df_rural["SUBZONE0"].tolist()
print(zone_rural)

# #In[10]:
df['URB_DEG']=df['location_id'].isin(zone_urban)
# # In[12]:
print(len(df.index))

# # In[13]:

# #migrating 5% population from rural to urban zones
# #total population = 6294755, 5% of population = 314738
df1=df.query("URB_DEG==False").sample(n=314738)

# # In[21]:
A=df1.index.values.astype(int).tolist()
df.drop(A,axis=0, inplace=True)
print(len(df.index))

# #In[24]:
B=random.choices(zone_urban, k=314738)
```

```
# #In[30]:
df1.drop('location_id', axis=1)

# #In[32]:
df1['location_id']=B

# In[34]:
#joining the changed location_id data to make full population
df=df.append(df1, ignore_index=True)

# In[35]:
print(len(df.index))

# In[36]
df.to_csv("Population_frac_5.csv", encoding='utf-8', index=False)
```

Appendix II

Declaration on Honor for accessing FEATHERS4 data/executable



UHASSELT

Declaration on Honour

I, student at Universiteit Hasselt (UHasselt) at the School of Transportation Sciences accept the following conditions and provisions of this declaration:

1. I am enrolled as a student at UHasselt in the program of Master of Transportation Sciences. During my enrollment as a student, I have the chance to contribute to research as part of my study program of the School of Transportation Sciences. This research is managed by prof. dr. ir. Tom Bellemans and is part of the course unit 4323 Master Thesis. As part of this research, I will produce creations, sketches, designs, prototypes and / or research results in the domain of transportation modeling (hereinafter: "The Research Results").

2. Whilst creating these research results, I will use background knowledge, confidential information[1], means and facilities of UHasselt (hereafter referred to as 'the Expertise').

3. I will only use the Expertise, confidential information included, for my research at UHasselt as mentioned in 1. of this declaration. I will always observe the applicable regulations, in particular the General Data Protection Regulation (EU 2016-679).

4. I will not use the Expertise (i) for any other purpose nor (ii) Make the Confidential Information public or disclose it to third parties, in a direct or indirect manner, without prior written approval from UHasselt.

5. As I am allowed to use the Expertise from UHasselt for the creation of my Research Results in the framework of the aforementioned research, I hereby assign all existing and future intellectual property rights -such as but not limited to: copy rights, patent rights, trademark rights, model rights and know-how,- to Universiteit Hasselt. This transfer of rights is done in the fullest extent, is applicable in any part of the world and for the entire period of protection of the relevant rights.

6. Should the Research Results be subject to copyright, the transfer referred to in 5. of this declaration shall include the following exploitation rights, applicable in any part of the world, for the entire period of protection of the relevant rights and without any compensation due :
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- The right of Universiteit Hasselt to edit and/or translate the Research Results in whole or partly (such as colour, contrast, size, settings, …), and to reproduce the edited or translated versions thereof;
- The right change the Research Results in whole or partly by reproducing certain elements by any and all techniques available and/or by changing certain parameters (such as colours and measurements).

The transfer of these exploitation rights is also applicable to future research results achieved during my research at UHasselt, for the entire period of protection, worldwide and without compensation.

I always reserve the right to be named as an (co) author in a publication.

7. For the implementation of my work, I commit myself to write down all the research data, ideas and findings in a "laboratory notebook" and not to expose these data unless with explicit approval of my supervisor prof. dr. ir. Tom Bellemans.

8. Upon completion of my research, I will return all the received confidential information and copies thereof, that would still be in my possession, to UHasselt.

Duly understood and accepted by :

Name: Eridona Selita

Address: Elfde-Liniestraat 15B, Hasselt, Belgium

Date: 15/02/2022

Signature: