Demonstrator of a Cost/Utility Function Taking Activity-based Information into Account

D4.2

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Short Description	*The report presents details of the integrated behaviour simulator especially in relation with their cost/utility function to address the type of policies/interventions it can assess. These policies are selected on the basis of earlier relevant deliverables where a comprehensive review is provided about their effectiveness in relation to air quality and also considering their relevance with the mobility situations within iSCAPE cities. Within these policies, some aggregated outputs of the implementation of specific scenarios, such as restricting car access in core city areas and enhancement of public transport infrastructure, parking regulations and telecommuting, are presented to demonstrate the capabilities of the behavioural simulator. The obtained results are found plausible and provide important inputs to be used in emission and air quality dispersion models for assessing impacts related to improvement of*

	air quality and exposure assessment.		
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ABM	Activity-based Model
AMOS	Activity MObility Simulator
DOW	Description of Work
DT	Decision Tree
FEATHERS	Forecasting Evolutionary Activity-Travel of Household and their Environmental RepercussionS
HBW	Home-based work
HBO	Home-based other
IPF	Iterative Proportional Fitting
LSOA	Lower layer super output area
MATISM	Multi-agent Transport Simulation
OD	Origin- Destination
P-CAT	Prism-Constraint Activity-Travel Simulator
PT	Public Transport
RUM	Random Utility Maximization
TAZ	Traffic Analysis Zones
TDM	Travel Demand Management
TEZ	Traffic Emission Zone
VKT	Vehicle kilometres Travelled
WP	Work Package

1 Executive Summary

This deliverable as part of WP 4 task 4.2.1 is having three major aims. Firstly, it presents a demonstration of an Activity-based model (FEATHERS) and its supply counterpart MATSIM, to predict activity-travel schedules of individuals and then execute them to determine the traffic volume on the road network. The deliverable provides a comprehensive description of cost/utility functions (i.e. functions that incorporates a variety of variables and associate them with travel decisions) to ascertain the type of policies/interventions or TDMs that can be assessed within the developed simulator. The cost/utility function with FEATHERS are in the form of decision tree models and within MATSIM it is represented as a scoring function of a plan based on a variety of built-in parameters. The deliverable also provides a guideline methodology about what possible changes in the system need to be made in order to run a particular policy scenario.

As a second major aim, the deliverable presents a criterion in order to select policies to be tested via the developed simulator. The criterion is mainly following the earlier deliverables where a complete review of such policies is provided that are found most effective in relation with improving the air quality of a certain region. Furthermore, support from iSCAPE city profiles that also presents the mobility situations of each city is taken to finalize the list of policies. These city profiles are based on the opinions of the city stakeholders and its citizens. In addition to this, the selection of policies is also based on the state-of-the art transport policy literature, which emphasizes more towards low-cost and easily implementable policies. Limitations of the simulator are also considered in finalizing the policy list. Restriction on car accessibility, enhancement of public transport infrastructure, fare reduction of public transport, road pricing, strict parking regulations, telecommuting and opening hours of activity locations are presented as key policies that have significant potential to bring positive change in the environment as well as individual's health.

Lastly, some of these policies are implemented in the simulator along with the presentation of aggregate results. Before the policy implementation, results of the base scenario are validated with available traffic counts, which are found plausible as goodness-of-fit measure is more than 0.7 in all validation cases. Results of the policies are also in line with the expectations. However, outputs can be disaggregated in a variety of different ways to discover more meaningful insights about the impact of policies. The aggregate outputs presented in this deliverable is for demonstration purpose and to provide evidence regarding the capabilities of the simulator.

For the next steps of WP 4, this deliverable can provide a profound basis to ascertain few policy scenarios to be run for a selected iSCAPE cities within a light version of this simulator whose development is ongoing as a part of task 4.2.2. Partners in iSCAPE cities are encouraged to discuss this deliverable with city stakeholders to come up with one or two policy scenarios that can be implemented for assessment of their impacts. Furthermore, in order to achieve the overall objectives of WP 4, the results obtained from the policy implementation will be further incorporated in emissions and air quality dispersion model to identify their impact on improving overall air quality for selected cities. These results can help in exposure assessments and to ascertain health impacts for various groups of population, which is required to be reported in WP 7 deliverables.

2 Introduction

This section describes the background and contextual details on which this deliverable for task 4.2.1 of work package (WP) 4 of the project is based. Furthermore, it describes the scope under which this deliverable is prepared keeping in view the description of work (DOW) for task 4.2.1. The DOW defines the task 4.2.1 as follows:

4.2.1: Selection of Travel Demand Measures (TDMs) and policy scenarios to assess
Potentially, activity-based models should be sensitive to several groups of TDM, including: population, schedule, opening-hours, land-use measures as well as travel costs and travel times scenarios. In terms of population scenarios, several large trends can be potentially evaluated, for instance the increasing participation of women in the labour force, the increasing number of single-adult households resulting in a decreasing average number of persons per household, the increasing household income as a consequence of general economic growth, the aging of the population in terms of greying and de-greening, the increasing number of cars per household etc. Also institutional changes in society, for instance by means of the implementation of a workweek (for instance 4 days instead of 5) or work start time changes (for instance starting at 9.30A.M. instead of 8A.M.) can be modelled in an activity-based framework. A similar application is the widening and shortening of opening hours of for instance service related facilities. Not only time-specific measures can be evaluated, but also spatial scenarios can be computed. For instance, there might be a need to evaluate the result of an increasing spatial separation of locations for residence, work and facilities as a consequence of sub-urbanization or alternatively, a concentration of facilities in commercially attractive neighbourhoods. As mentioned before, in addition to the measures mentioned above, this research proposal significantly widens the applicability of TDM which are related to environmental and health effects, using the activity-based paradigm as a starting point.

The text for task 4.2.1 primarily mentions a wide variety of TDMs that are reported in the mobility literature and many of them can be tested and implemented using an Activity-based model. The title of the task, however, specifies that some of these TDMs are required to be selected by following some meaningful criteria, and out of these selected policies few policy scenarios can be assessed. In addition to this, the title of the deliverable 4.2, further indicates that it demonstrates the cost/utility functions exists within ABM in a way that helps in developing an understanding about the type of policies/TDMs/interventions can be assessed using such a simulation tool.

Based on the above discussion and further considering the overall objectives of WP 4, within this deliverable, three major aspects are required to be accomplished. These are as follows:

1) A comprehensive as well as easy to understand explanation is required to be provided about the cost/utility functions of a simulator that takes into account activity-based information.
2) In relation to the selection of TDMs, a criterion needs to be discussed and based on that a list of policies are required to be recommended. Some of these policies are devised in a shape of a scenario and their assessment needs to be provided using a simulation tool.
3) The deliverable should demonstrate the functionality of the simulator, so that it can serve as a guiding document for partners in iSCAPE cities, so that they can pick one or two relevant policies which can be implemented and their impacts can be assessed with a light version of such model (this is committed in task 4.2.2) for other selected iSCAPE cities to fulfil overall objectives of WP 4.

2.1 Scope of the Deliverable

This deliverable is prepared to accomplished the requirement of the three major aspects discussed above. Below we list the main scopes of this deliverable.

1) To explore a variety of TDMs/policies, this deliverable provides in fact the methodology for testing these policies within the framework of the development of an integrated behavioural simulation model that integrate two models: FEATHERS as a demand side activity-based model and MATSIM as a microscopic agent-based supply model. This

integrated simulator is developed for Flanders region that also includes an iSCAPE city (i.e. Hasselt). The simulator is calibrated using a variety of datasets such as household travel survey of Flanders region, land use and level of service data. Moreover, the model results are also validated with available traffic counts.

2) Criteria for the selection of policies will be based on the recommendations of some earlier deliverables of the iSCAPE project and emphasis on some policies within the transport policy literature.

3) To explore the cost/utility functions of the models and to demonstrate their potential use to assess a variety of TDMs specific details are provided about what changes are required in the data and models. It is not in the scope of this deliverable to analyse the effects of all discussed policies by executing them in the simulation process. These analyses will be carried out as next steps in WP 4 and specifically deliverables 4.3 and 4.4 will contain more details on this.

4) This deliverable should be considered as a building block for the subsequent work to be conducted within WP 4 and whose results will be described in deliverables 4.3 and 4.4 where the developed behavioural simulator will be further integrated with emissions and pollutant dispersion models and some of the policies mentioned in this deliverable will be tested within the complete chain of models

5) The policies /intervention discussed in this report are presented in a manner that can be easily simulated and implemented within the behavioural simulator developed/calibrated for Hasselt city. For the other iSCAPE cities, a light version of the ABM will be developed as part of task 4.2.2, from which some of the mentioned policies may be executed/implemented; however, results from such light model will be more aggregated and not very detailed as in the case performed with the complete agent-based integrated FEATHERS + MATSIM. Therefore, the focus of this deliverable is to discuss all relevant policies and how they can be tested/assessed within the developed behavioural simulator.

2.2 Layout of the Report

The report is structured along six key sections. Section 3 presents the characteristics and features of the Activity-based model and describes in details the cost/utility functions for the FEATHERS model developed for the Flemish regions that include the city of Hasselt. These cost/utility functions are models where socio-economic and network performance variables are associated with a variety of activity-travel decisions of individuals, thus providing an idea about what kind of different interventions can be tested from such tool. Section 4 presents the details of the integration of FEATHERS with MATSIM model. MATSIM functionality is described in detail and then the integration framework is discussed. The integration of FEATHERS and MATSIM is carried out for the entire Flanders regions, and the results for the Hasselt city can be extracted from the overall results. Furthermore, details of the scoring function that can be considered as a cost/utility function within MATSIM are presented to illustrate more clearly the type of variables incorporated within the models and how they can be used to assess a variety of different policies. Section 5 presents a variety of different policies/interventions with the presentation of some aggregate results and mainly demonstrates the ways in which these can be implemented in the integrated behavioural simulator for their assessments. Initial sub-sections within section 5 describes the validation of integrated model results from available traffic counts and also discuss why some policies are chosen for their assessment. Section 6 concludes the deliverable and puts forward some recommendations for the next deliverables of the WP 4 of the iSCAPE project.

3 Activity-Based Model

The activity-based Model (ABM) is based on the notion that *travel is derived from the need to participate in activity [Ben-Akiva and Bowman, 1998].* In other words, ABMs are based on the fact that it is the desire to participate in activities that lead to its associated travel. Therefore, the fundamental aim of an ABM is to determine, for all individuals, the sequence of activities including its relevant components such as when, where and with whom they are performed [*Rasouli and Timmermans, 2014*]. A typical ABM considers the complete daily activity-travel pattern of individuals living in the study area. This includes, for each agent in the synthetic population, the number of activities to be performed and specific attributes of each activity: type, start time, duration, and location. Furthermore, these simulated activities are also linked together via a travel component having its own dimensions: travel time and travel mode. Hence, the ABM approach attempts to analyze travel demand in a disaggregated fashion. Furthermore, the integrity between various sub-models, the interdependency between activity and its associated travel and the inclusion of a more detailed timingwithin the ABM make it superior to the conventional approach of travel demand modeling. More details are described in the next few sub-sections of this section.

3.1 Why Activity-based Model?

The most widely used travel demand models are the four-step model [*de Dios Ortuzar and Willumsen, 2011*] often called as a trip-based approach in the literature. This model type predicts the travel demand in the following four steps:

1. The first step is the trip generation. In this step, the home-based and non-home based trips are generated from and attracted to each Traffic Analysis Zone (TAZ) in the study area. TAZ are usually generated by dividing the study area into small homogenous land use area. It is recommended that TAZ usually have population of around 1000 to 2000 inhabitants. Usually transport models uses small administrative boundaries of the cities as TAZ. In case of UK, lower layer super output area (LSOA) are usually taken as TAZ. Often regional demographic data is available based on these small areas. Therefore, transport model considered this as a spatial unit within the study area.
2. The second step is the trip distribution, which distributes all trips between origin-destination (OD) pairs according to trip production and attraction. The first two steps together represent an aggregate travel demand in the form of an OD matrix. The element of the matrix represents trips originated from one TAZ and destined to another TAZ in the study area. The diagonal of the matrix represents trip originated and destined in the same TAZ.
3. In the third step, the trips are distributed according to each type of mode on the basis of a mode choice model.
4. Lastly, the trips are assigned to the road network and the traffic flows are obtained. For a detailed discussion of all the steps the readers may refer to the Book *Modelling Transport* by Ortuzar and Willumsen (2011, p. 139).

Although common in practice, there are several issues which are part and parcel of the four-step model [*Siyu, 2015, Rasouli and Timmermans, 2014*]. These issues can be summarized under four categories:

- Lack of integrity: the early four-step models were not linked together. For example, the travel time obtained from the traffic assignment is different than the travel time used in other models for assigning trips.

- Aggregate nature: in a four-step model, the TAZs are the unit of analysis; all trips are generated and attracted at TAZs.
- No interdependency: in a four-step model, each trip generated is considered as a separate entity. Thus, there is no trip chaining characteristics and no link between the trips generated.
- Behavioural realism: four-step model is built on the mechanism that is observed in natural sciences, such as trip attraction through a gravity-based model. Similarly, it ignores logical restraints, e.g. a person going to work by car will use the same mode for the return trip and institutional constraints, e.g. shopping trips can only be performed during the opening hours. In addition, it generates demand as a regression on zonal properties rather than trying to capture (individual) behaviour.

Over time, there has been a substantial improvement in the four-step modelling approach with regard to these limitations. For instance, to address the issue of lack of integrity, the travel times obtained from traffic assignment are then used in other models (also referred as the feedback loop). Similarly, individuals (in a TAZ) are used for trip generation and separate demand is generated for peak and off-peak time. However, the four-step model is still aggregate in nature. The impact of these weaknesses of trip-based approach is relatively small in a supply-oriented planning process where the focus of transportation planning is to provide adequate transportation infrastructure with intensive capital investment i.e. building new roads, increasing number of lanes on existing infrastructure to facilitate more cars and private traffic. However, in recent times due to lack of resources and monetary funds, there is a paradigm shift in the transportation planning process as planners and practitioners are more focused to introduce demand management measures for solving transportation problems[*Guzman et al., 2016*]. Examples of such notions are emphasizing in provision of multi-modal integration, enhancing public transport network [*Fellermann, 2015*], pricing road usage [*TfL, 2007a*], telecommuting [*Zhu and Mason, 2014*], flexible working hours schemes, bicycle infrastructure and vehicle sharing schemes [*Tang et al., 2011, Zhou, 2012*]. Under these circumstances, the advantages of activity-based models provide planners with a useful tool to assess the impact of these policies/interventions.

3.2 Activity-based Model Framework

This section outlines the overall framework and model structure of the activity-based travel demand model. Within this framework, there exists a variety of models, almost all of which are formulated through a system of interconnected sub-models/components that predicts different decisions related to daily activity and mobility. This section describes the overall modelling inputs, data requirements, and simulation requirements.

People make activity and travel decisions within many spatial and temporal dimensions. Long-term decisions, such as choice of residential location and vehicle ownership, are taken for the longer time period e.g. yearly or even much longer than a year due to the involvement of significantly high cost and stake. Mid-term decisions, refer to the decisions that are made and updated on daily basis. Decisions in this group focus on daily activity and mobility. The Activity-based model is a disaggregate travel demand system designed to model mid-term decisions. Decisions made in the long-term are taken as an input for ABM. Figure 1 shows the model components and process flow of a typical ABM. Synthetic population with known socio-demographic characteristics is an input to the system. Other inputs include network skims, land use characteristics, etc. Those inputs are discussed subsequently.
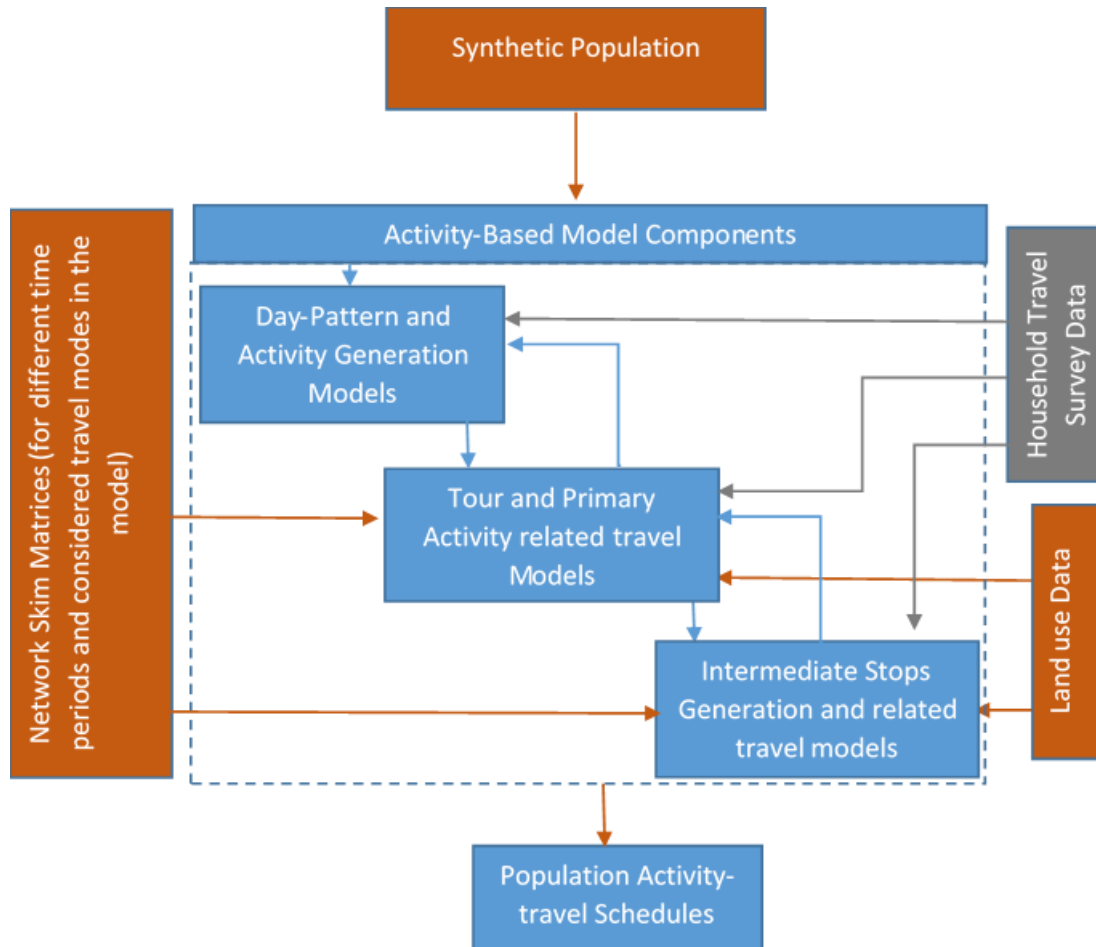
Figure 1: Activity-based Model Framework with Required Modelling and simulation Inputs

3.2.1 Modelling and Simulation Inputs

A variety of data is involved in the development of an activity-based model. More details regarding each input are provided below:

Household travel survey data: This data remains the main data source for modelling as the individual models in an activity- based modeling framework are all estimated from household travel survey. In Figure 1 this is shown with a grey box with arrows starting from this box and pointing towards the different model components of the ABM. The household travel survey data contains information about individual and household level socio-economic attributes (these characteristics are also part of synthetic population, see Table 1 for more details) and also travel details of the individuals e.g. where they have travelled, which activities they have performed in a given day, how (travel mode) and when (time of the day) they have traveled. Usually planning agencies conduct this kind of survey every four/five years in a particular region for a population sample. Nowadays more advanced tools such as GPS based smartphone applications are also used to obtain such information. Different models in the ABM are developed by making an association between individual/household characteristics and these travel decisions. Network skims and Land use data are also combined to develop such associations.

Network skims: The level of service information used in estimating the choice of the travel mode and time of day models is derived from network skims. Urban transportation planning agencies usually maintain travel time matrices (or skims) for a small number of pre-determined

time windows, such as AM peak, PM peak, and off-peak, generated after the calibration of volume-delay functions (based on measurements from e.g., floating car data) and the assignment of OD matrices to the network for a number of time periods. Those skims contain zone-to-zone travel time, travel distance, travel cost (tolls if any) and public transit fares matrices.

Land use data: Land use data is important for the modeling of destination choice of activities. This data provides information used to build attraction variables included in destination choice models. The destination choices within ABM are based on TAZ. A list of land use parameters is attached to each TAZ. For example, the number of shops, number of schools, number of workers, number of recreational places with their areas etc.

Synthetic Population: This is the main data required for the simulation purpose. ABM model uses this data as input to predict outcomes for each member of the population, and finally aggregates the results for policy analysis. Usually, Iterative proportional fitting (IPF) algorithms are used to create a synthetic population. The typical synthesis procedure involves two main steps: first, a demographic distribution of households is estimated for each TAZ or census block group, and then a matching sample of households is drawn from a set of household records for which nearly complete census information is available. This produces a synthetic population in which each synthetic household and its members have many clearly defined characteristics for use in the model system, and together they match the estimated demographic distribution within each TAZ.

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

Table 1: Example of attributes for each agent in the synthetic population

3.2.2 Modelling Approaches

According to [*Siyu, 2015, Rasouli and Timmermans, 2014*], in relation to the modellig approach, ABMs can be classified as follows:

1) Econometric models,

2) Rule-based models

3) Hybrid models

3.2.2.1 Econometric Models

The econometric approach uses the Random Utility Maximization (RUM) Theory that anticipates individuals to make a rational decision with complete information about each available alternative. The econometric models can be further categorized into two sub-types: those where the individual acts as the sole activity-travel decision-maker and those where the interactions between households and individuals are also considered. Such interactions can be related to task allocation, vehicle allocation, joint activity participation, escorting children to school and social interactions in some advanced cases. Models based on this approach predict the probability of each alternative for the individual and then a Monte-Carlo simulation approach is used to allocate a particular alternative to the individual/agent in the synthetic population. Day-Activity model [*Ben-Akiva and Bowman, 1998*], and SimMobility Mid-term [*Adnan et al., 2016*] are examples of econometric models.

3.2.2.2 Rule-based Models

The rule-based models, as evident from their name, employ heuristic rules to simulate the original decision-making process. STARCHILD is considered as the first rule-based ABM that determines the activity-travel pattern in three stages [*Recker et al., 1986*]. It first generates the individual activities, then an activity-pattern choice set is generated, and lastly, the choice set is reduced by grouping activities together.

SCHEDULER organizes short-term activities according to their priority such as to reduce the overall travel distance [*Axhausen and Gärling, 1992*]. SMASH employs a Nested Logit model to add activities along with their characteristics (location, mode, route and time). It starts with an empty schedule and adds activities sequentially.

Activity MObility Simulator (AMOS) was developed at Arizona State University with the motivation to evaluate TDM strategies like secondary and tertiary impacts such as the impact of changes in the activity-travel pattern on other household members and the environment. AMOS is now improved into a full-fledged activity-based travel demand model as Prism-Constraint Activity-Travel Simulator (P-CAT). PCAT is also in use at Nagoya and Kyoto University, Japan. P-CAT first generates an activity-skeleton which includes fixed activities such as work and education. The other flexible activities are generated for the open time-space prisms. Currently, it is now available as open-source (Open AMOS). FEATHERS and ALBATROSS are also rule-based ABMs that rely on Household travel survey data for formulating rules [*Bellemans et al., 2010, Arentze et al., 2002*]. A detailed framework of FEATHERS model used further as an ABM in iSCAPE WP 4, is described in section 3.3.

3.2.2.3 Hybrid Approach

This category groups activity-based travel demand models that incorporate more than one of the approaches described above. Such an approach allows to improve different sub-models using the optimal approach. Therefore, this is considered as the most comprehensive approach towards ABM. Travel/Activity Scheduler for Household Agents (TASHA) [*Roorda et al., 2008*] and ADAPTS model [*Auld and Mohammadian, 2012*] are examples of this approach. The ADAPTS model blends together the two approaches defined above. Furthermore, the ADAPTS framework also has a model for activity planning where the activities are discretely planned and modified over time.

3.3 FEATHERS: Cost/Utility Function Details

This section describes a framework to simulate residents' travel decisions as part of the complete activity-travel schedule in FEATHERS which is operational for Flanders, Belgium. Figure 2 shows the key modelling components of FEATHERS .
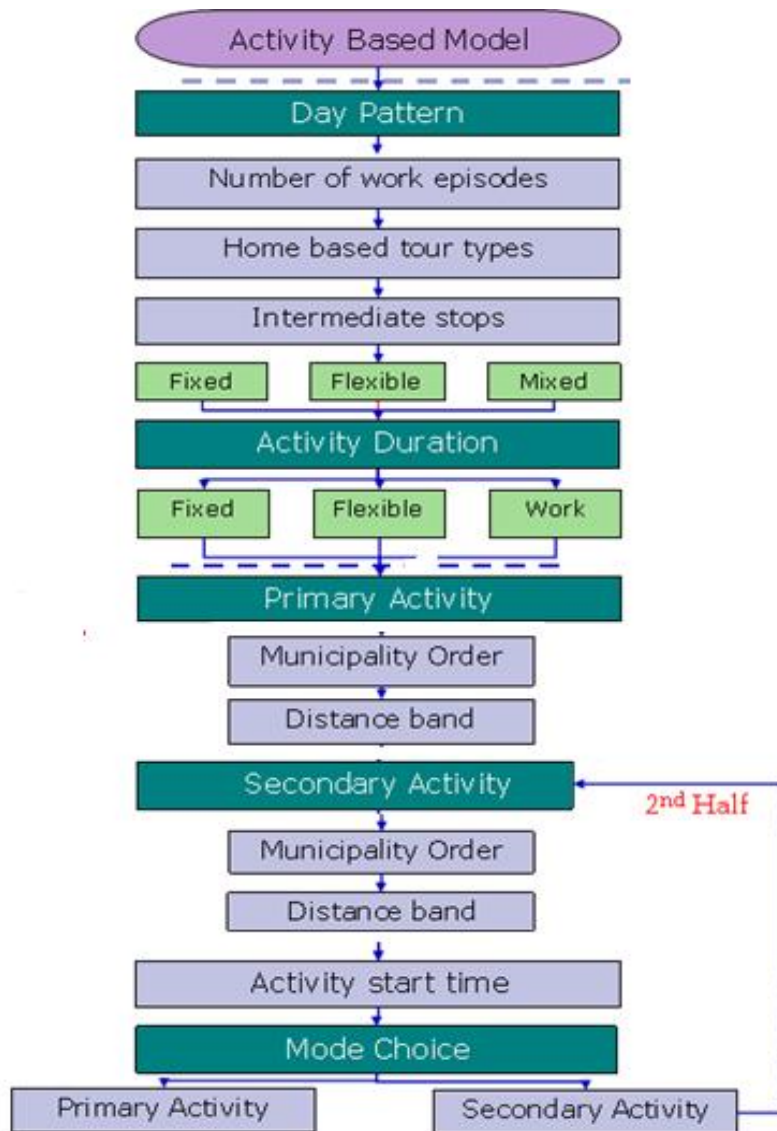
Figure 2: FEATHERS Schematic Framework for Key Scheduling Models (Adapted from [Baqueri, 2018])

First, within the day pattern model, the number of work episodes followed by the home-based tours are determined. Then, for each tour, intermediate activities along with their location (i.e. before or after the tour's primary activity) are determined. The intermediate activities are categorized as fixed [bring, get, other] or flexible [shopping, services, social, leisure and touring]. Once each activity in the schedule is determined, its duration is modeled. The spatial units are defined in FEATHERS at three levels: superzones (municipalities), zones (city) and subzones (TAZs). Depending on the size, a municipality may contain more than one city and a city may contain more than one TAZs. For the choice of the destination, a multi-level decision hierarchy is used to specify the location of an activity i.e. at an initial stage a model is used to determine

municipality order and then another model is used to predict a distance band. A TAZ is randomly decided within the predicted distance band. The last step before the choice of the mode is the activity start time hour. At this step, 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 last decision is related to the transport mode for each activity. For each sub-decision model, the schedule decisions simulated earlier are also included as explanatory variables.

Each sub-model in FEATHERS is built using a Decision Trees (DT) approach. **These DT can be considered as a cost/utility function involved within FEATHERS**. For this reason, we are providing more details on it, so that the capability of FEATHERS can be easily understood. Available methods in statistics and machine learning can be used to induce a decision tree from data. A decision tree is developed by recursively splitting a sample of observations into increasingly homogeneous groups in terms of a given response variable. A similar approach was used in the development of the ALBATROSS model [*Arentze et al., 2002*]. 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. Table 2 shows the names given to different decision trees involved in the FEATHERS framework. These decision trees are developed using the household travel survey data of the entire Flemish region.

S. no.	Decision Trees involved in FEATHERS FRAMEWORK
1	Choose Number Of Work Episodes
2	Choose Home-Based Tour Types Sequence
3	Choose HBWI1 Intermediate Stop Activities (HBW stands for home-based work tour)
4	Choose HBWI2 Intermediate Stop Activities
5	Choose HBWI12 Intermediate Stop Activities
6	Choose HBO Intermediate Stop Types Fixed Flexible Mixed (HBO stands for home-based other tour)
7	Choose HBO Intermediate Stop Activities Fixed
8	Choose HBO Intermediate Stop Activities Flexible
9	Choose HBO Intermediate Stop Activities Mixed
10	Choose Duration First Work Activity
11	Choose Duration Second Work Activity
12	Choose Duration Fixed Activities
13	Choose Duration Flexible Activities
14	*Choose Primary Location In Home Municipality*
15	*Choose Primary Location In Home Subzone*
16	*Choose Order Municipality*
17	*Choose Nearest Order Municipality*
18	*Choose Distance Band Superzone*
19	Choose Start Time Hour of Home Based Tour Primary Episode
20	*Choose Transport Mode Primary Episode*
21	*Choose Secondary Location In 1st half*[+]

22	Choose Start Time Hour of Home Based 1st Half Tour Secondary Episode
23	Choose Transport Mode Secondary Episode 1st half tour
24	*Choose Secondary Location In Study Area 2nd half*
25	Choose Start Time Hour of Home Based 2nd Half Tour Secondary Episode
26	Choose Transport Mode Secondary Episode 2nd half tour
27	Choose Start Time Hour of Home Based Tour Last Home Episode
28	Choose Transport Mode of Home Based Tour Last Home Episode

Table 2: Decision Trees involved in FEATHERS Framework

As an example, Figure 3 shows a possible decision tree for the model *Choose Transport Mode Primary Episode.* An important aspect to note here is that all continuous variables used in the model are converted into discrete variables. In this example, travel cost is divided into three classes. The example starts from the travel related attribute (such as travel cost/km, an information available from previously decided location of activity derived from the earlier model in the decision hierarchy) and then based on some characteristics of individual and household (i.e. Gender and car ownership, details available from the synthetic population), the tree is further prolonged to decide about travel mode when travel cost is cheaper. This example is provided just for illustration as DTs involved in FEATHERS are much more complex and dependent on a variety of different variables from the different data sources previously described in section 3.2.1.
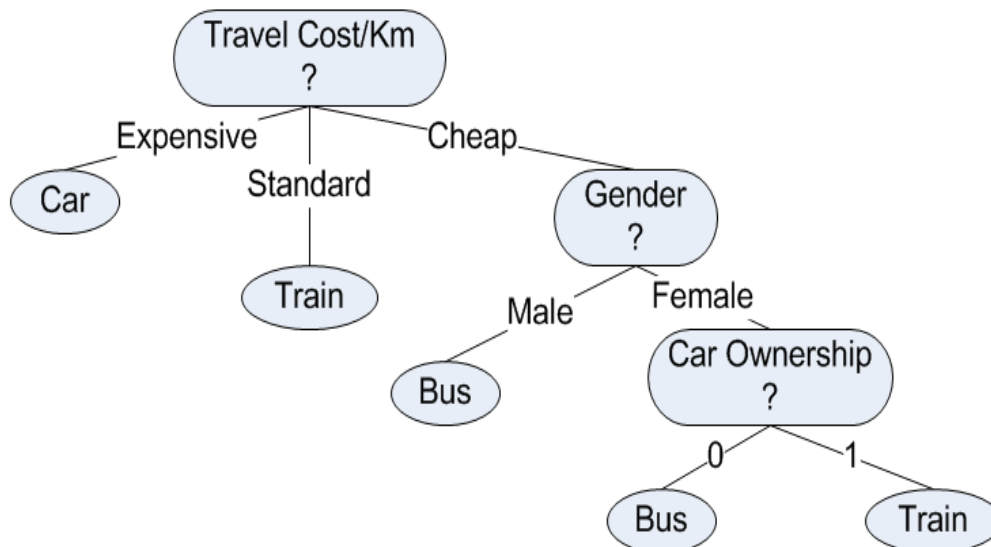
Figure 3: DT for Travel mode Decisions (Example adopted from [Tecknomo, 2009])

Outcomes from all DTs are then accumulated to predict the complete activity-travel schedule of an individual. The simulation is then performed for all individuals in the population. As an example, the schedule for a random individual can look like as the following model output:

Individual ID: 00001
3:00 am; home(zone 1)……7:30am; trip to work using car (zone1 to zone 4),… 7:45am; arrival at work (zone 4)…..5:40pm; trip to home using car (zone 4 to zone 1)…..5:55pm; arrival at home(zone 1), ….8:00pm; trip for dinner using car (zone 4 to zone 6)…8:15pm;arrival at restaurant(zone 6)…9:45pm; trip to home using car (zone 6 to zone 1)…..10:00pm; arrival at home (zone 1)…..next day….3:00am; home (zone 1)

4 Integrated Travel Behaviour Simulation Model

Traditionally, the outputs of ABM (i.e. travel schedules of agents) are aggregated in terms of time-dependent OD matrices that are fed into the supply model (such as TRANSCAD) to estimate flows and travel times on the road network [*Castiglione et al., 2015*]. There are several disadvantages of such an approach like the loss of disaggregation at supply level which does not allow the explicit representation of individuals decisions related to route choice and other en-route decisions [*Adnan et al., 2016*]. Furthermore, detailed outputs from supply model (especially in relation with policy) cannot be classified based on the socio-economic attributes of the individuals. Increase in computational power and availability of big-data source have allowed developments towards large-scale integrated simulation models within the transport planning practice. These models allow explicit consideration of individual decision processes at both levels (i.e. demand and supply levels).

4.1 FEATHERS and MATSIM Integration

Before discussing more on integration, the following section first describes the MATSIM platform in details and its important features.

4.1.1 MATSIM

MATSIM is an activity-based, extendable, multi-agent and open-source simulation framework implemented in Java. According to [*Horni et al., 2016*], it is based on the co-evolutionary principle. Agents are optimizing their daily activity schedule by competing for space-time slots with other agents on road network. This is similar to route assignment in iterative fashion as done by other supply models (which are dynamic); however, MATSIM ensures agents identification within the network and also changes some dimensions of the activity schedules (such as time, mode and destination choices of activities) to bring the overall system to optimality.

MATSIM requires as input as the so called initial plans (activity-schedule of an agent), which are output of FEATHERS or other ABMs. It also requires a complete transport infrastructure (such as road network with its essential details, Public transport fleet and operations data, signals data with green and red times in different time periods) to perform network assignment process. Apart from this input there is a range of parameters that can be considered as part of scoring module. Each agent plan is given a certain score, and MATSIM iteratively optimizes the score of a plan for each agent by slightly changing dimensions of activity-schedule in an iterative manner. Figure 4 illustrates the way MATSIM works in a loop. Mobsim is the module that executes the plans on the road network.
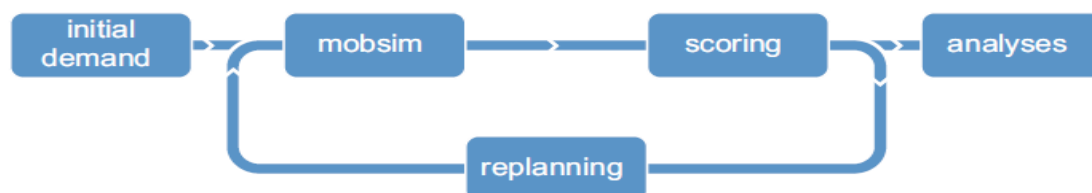

Figure 4: The MATSIM Cycle (Adopted from [Horni et al., 2016])

4.1.2 FEATHERS + MATSIM

MATSIM has been integrated with a variety of other ABMs. Coupling ABM and traffic models together is often considered natural as one provides the required inputs to the other. As such, FEATHERS provides the population and activity-travel schedule of each agent in the population which are considered as initial plans in the MATSIM. In return, MATSIM executes these plans/schedules on the road network and estimates travel times. These travel times are converted into skim matrices and fed-back to FEATHERS. FEATHERS uses the new skim matrices and predicts new activity-schedules for each agent. These FEATHERS-MATSIM cycles run a few times so that outputs from each model are consistent. This cycle is shown in Figure 5. It has been proved that within MATSIM iterations (called as inner iterations) can be reduced if the model is provided with more optimal initial plans. The outer iterations take care of this additional information as plans are predicted using the travel times from the MATSIM model. This method is much faster in reaching consistency and outputs are considered more realistic in comparison to providing MATSIM with initial plans drawn from collected data of sampled population. Furthermore, the integration paves the way to assess a variety of policy scenarios using a wide spectrum of outputs. This is further explained in section 4.2.
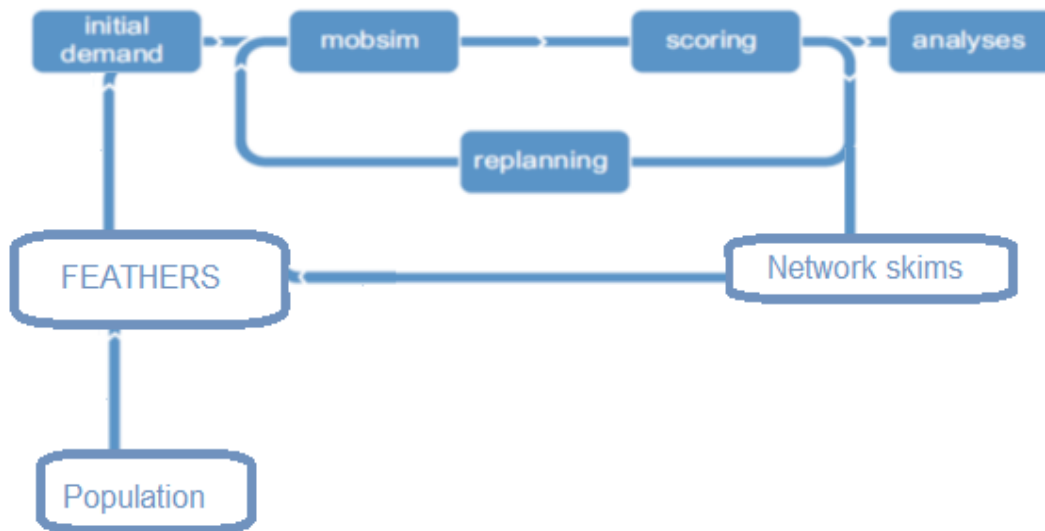
Figure 5: FEATHERS + MATSIM Integration

4.2 Cost/Utility Functions Details for Policy Assessment

The cost/utility function of FEATHERS have been discussed in detail already in section 3.3. The focus here will be on MATSIM model. Furthermore, this section also discusses how the impact of the policies can be forwarded to scheduling dimensions within FEATHERS when it is integrated with MATSIM. Usually, when MATSIM is integrated with ABM, the choice of mode, destination and the addition or deletion of activities are considered fixed as they are changed within FEATHERS. Therefore, within MATSIM only the time-of-day dimensions can be changed, which also implicitly change the duration of activities. The major dimension that MATSIM can predict is the route taken by an agent to reach a particular destination to perform an activity in his/her plan.

The cost/utility function used within MATSIM is called scoring functions for various activity scheduling dimensions. These functions are used to calculate the overall score of plans that have been executed by Mobsim. Each agent may have more than one plan: the higher the score of the plan, the higher the chances of selection and execution within Mobsim. Initial few iterations within the MATSIM are performed only to get the score of the initial plans and to generate the number of plans for each agent with slight modification (changes in route and time-of-day dimensions). The score of the plan, S_{plan} is calculated through the following basic function.

$$S_{plan} = \sum_{q=0}^{N-1} S_{act,q} + \sum_{q=0}^{N-1} S_{trav,mode(q)} \qquad (1)$$

Where, $S_{act,q}$ is the utility of activity q in the plan and $S_{trav,mode(q)}$ is the disutility of travel by using a particular mode to participate in an activity. All activities utilities and travel dis-utilities are summed together to obtain the S_{plan}. N is the total number of activities in the plan.

4.2.1 Activity Utility functions details

The utility of an activity q is calculated as follows:

$$S_{act,q} = S_{dur,q} + S_{wait,q} + S_{late.ar,q} + S_{early.dp,q} + S_{short.dur,q} \qquad (2)$$

As mentioned in *Nagel et al.* [*2016*], each component of activity utility is described below:

$$S_{dur,q} = \beta_{dur}.t_{typ,q}.ln(t_{dur,q}/t_{0,q}) \qquad (3)$$

$S_{dur,q}$ is the utility of performing activity q, where opening times of activity locations are taken into account. $t_{dur,q}$ is the duration of the performed activity, β_{dur} is the marginal utility of activity duration and $t_{0,q}$ is the duration when utility starts to be positive.

$$S_{wait,q} = \beta_{wait}.t_{wait,q} \qquad (4)$$

$S_{wait,q}$ is the utility/disutility of time spent waiting to start activity q, for example, waiting in front of a still-closed store. β_{wait} is the so called direct marginal utility of time spent waiting and $t_{wait,q}$ is the waiting time.

$$S_{late.ar,q} = \begin{cases} \beta_{late.ar} \cdot (t_{start,q} - t_{latest.ar,q}), & if\ t_{start,q} > t_{latest.ar,q} \\ 0, & else \end{cases} \qquad (5)$$

$S_{late.ar,q}$ specifies the late arrival penalty. $t_{start,q}$ is the activity start time and $t_{latest.ar,q}$ is the last possible penalty-free activity start time.

$$S_{early.dp,q} = \begin{cases} \beta_{early.dp} \cdot (t_{end,q} - t_{earliest.ar,q}), & if\ t_{end,q} > t_{earliest.dp,q} \\ 0, & else \end{cases} \qquad (6)$$

$S_{early.dp,q}$ is representing the penalty for not staying long enough. $t_{emd,q}$ is the activity end time and $t_{earliest.dp,q}$ is the earliest possible activity end time.

$$S_{short.dur,q} = \begin{cases} \beta_{short.dur} \cdot (t_{short.dur,q} - t_{dur,q}), & if \ t_{dur,q} > t_{short.dur,q} \\ 0, & else \end{cases} \quad (7)$$

$S_{short.dur,q}$ is representing the penalty for too short activity. $t_{short.dur,q}$ is the shortest possible activity duration. The configuration file of the MATSIM contains the following default values of the parameters involved in the calculation of activity utility for each activity type (see Figure 6).

```
<module name="planCalcScore" >
    <param name="performing" value="6.0" />
    <param name="waiting" value="-0.0" />
    <param name="lateArrival" value="-18.0" />
    <param name="earlyDeparture" value="-0.0" />
    <parameterset type="activityParams" >
        <param name="activityType" value="work" />
        <param name="typicalDuration" value="08:00:00" />
        <param name="openingTime" value="07:00:00" />
        <param name="latestStartTime" value="09:00:00" />
        <param name="closingTime" value="19:00:00" />
        ...
    </parameterset>
    ...
</module>
```

Figure 6: MATSIM Configuration File: list of parameters for activity utility

4.2.2 Travel Disutility function details

Travel disutility for performing the activity q is given by

$$S_{trav,q} = C_{mode(q)} + \beta_{trav,mode(q)} \cdot t_{trav,q} + \beta_m \cdot \Delta m_q + \left(\beta_{d,mode(q)} + \beta_m \cdot \gamma_{d,mode(q)} \right) \cdot d_{trav,q} + \beta_{transfer} \cdot X_{transfer,q} \quad (8)$$

where:

- $C_{mode(q)}$ is a mode-specific constant
- $\beta_{trav,mode(q)}$ is the direct marginal utility of time spent traveling by mode
- $t_{trav,q}$ is the travel time between activity locations q and $q + 1$
- β_m is the marginal utility of money (normally positive)
- Δm_q is the change in monetary budget caused by fares, or tolls for the complete leg
- $\beta_{d,mode(q)}$ is the marginal utility of distance (normally negative or zero)
- $\gamma_{d,mode(q)}$ is the mode-specific monetary distance rate (normally negative or zero)
- $d_{trav,q}$ is the distance travelled between activity locations q and $q + 1$

- $\beta_{transfer}$ are public transport transfer penalties (normally negative)
- $X_{transfer,q}$ is a 0/1 variable signalling whether a transfer occurred between the previous and current leg

The configuration file of the MATSIM contains the following default values of the parameters involved in calculation of travel disutility for each mode

```
<module name="planCalcScore" >
   <param name="marginalUtilityOfMoney" value="1.0" />
   <param name="utilityOfLineSwitch" value="-1.0" />
   <parameterset type="modeParams" >
      <param name="mode" value="car" />
      <param name="constant" value="0.0" />
      <param name="marginalUtilityOfDistance_util_m" value="0.0" />
      <param name="marginalUtilityOfTraveling_util_hr" value="-6.0" />
      <param name="monetaryDistanceRate" value="-0.0002" />
   </parameterset>
   ...
</module>
```

Figure 7: MATSIM Configuration File: list of parameters for travel disutility

It is important to note that the choice of mode and destination has been kept fixed for this integration. However, as the choice of the time-of-day is not fixed, both activity and travel utility functions values will change and hence scores are different. In case of travel disutility, it will change because the value of travel time, which is an input in the function, may change for every different time interval. In case of activity utility, change in time-of-day may result in any of the following i.e. early arrival, late arrival or waiting and therefore the score will change.

4.2.3 Other Parameters

Apart from the above explained parameters, the following parameters/data are also part of the MATSIM configuration or inputs. Change in these parameters may result in different outcomes for the same case:

1. **Network details:** for example capacity of the link, number of lanes, lane width, link specific to particular type of mode (e.g. on motorway, bicycles are strictly not allowed).
2. **Route Choice Function/extensions:** By default, route choice depends on the shortest travel time between the origin and destination. However, there are functions/extension available when different other set of preference parameters can be used to define this phenomenon more explicitly.

5 Demonstrating Assessment of Policy Scenarios

This section discusses details regarding the implementation of different policy scenarios with the integrated behaviour simulation model that is developed and calibrated for Flanders region which also include Hasselt (an iSCAPE city). Before discussing the application of policies, it is vital to describe the validation of such an integrated model, so that results obtained from the analysed policy can be considered plausible.

5.1 Validation of an Integrated model

Usually, transport models are validated with a variety of different datasets. Most common validation dataset is considered as the traffic counts collected at the mid-section or at the intersection of important roads of the network. Transport authority/agency of the city or region usually collected this data in regular intervals, and sometimes loop detectors/sensors are installed in the pavement to collect such data on a continuous real-time basis. The models within FEATHERS and MATSIM for Flanders regions are calibrated with datasets such as household travel survey, and other available datasets. In order to validate the obtained outputs in terms of traffic volume, it is compared with traffic volumes available for various times of day at key points of the whole Flanders region. Figure 8 presents the availability of traffic counts for more than 400 location across the road network of Flanders covering the important section of motorways, expressways and national roads.

Figure 8: Traffic Counts location across Flanders

The results of the validation of these traffic counts are shown in figure 9. Consistent results are obtained at various time slots as Goodness-of-fit in terms of R-square is more than 0.7 in all comparisons. It is important to note that this validation is done for car traffic because the available traffic counts only contain data of this vehicle.
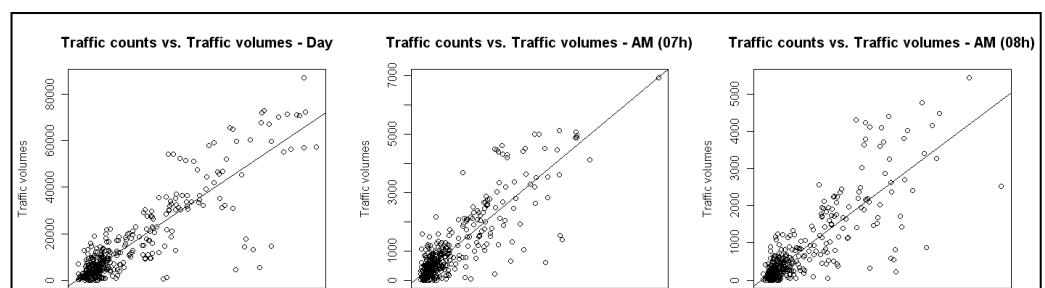
Time slot	R^2
24 hours	0.782
AM - 07h	0.743
AM - 08h	0.749
PM - 16h	0.742
PM - 17h	0.758
OP	0.778

Figure 9: Validation of obtained outputs with traffic counts

5.2 Selection of Policies for Assessment

The policies discussed in the next few subsections are selected based on the following notions:

1. ***Recommendations of deliverable 1.3:*** In deliverable 1.3 of the iSCAPE project, mobility-based behavioral interventions are reviewed at length from the existing literature. All the examined interventions are assessed in terms of their impacts on solving mobility problems as well as improvement in terms of overall air quality in the regions where these are implemented. An attempt is made to rank these interventions in terms of their effectiveness for reducing air pollution. Based on that, a policy of Traffic Emission zones (vehicles which are not operating on clean fuel sources are not allowed to enter into the emission zone) is found most effective. According to the deliverable 1.3, the second most effective set of policies are those which are implemented to promote the use of public transport. Within these, policies that are directly dealing with public transport such as its infrastructure enhancement, reduction in fares are more effective than policies which are to pricing such as road pricing, increase in parking fees and other taxations related to car use, so that people may shift towards using public transport. The next few sub-sections are, therefore, discussing how to assess variants of such policies from the simulator and also few examples are provided/implemented with the presentation of some aggregated outputs to demonstrate simulator capabilities.

2. ***Findings of Deliverable 1.1:*** This is another key deliverable within iSCAPE project. The deliverable attempts to presents profiles of all six iSCAPE cities in a variety of aspects that also include notions of mobility. The deliverable mentioned that all six iSCAPE cities are designed in such a way that they facilitate movements of car. Almost in each city, more than 50% of trips are conducted by car. Therefore, in these cities, policies that promote the use of public transport and restrict car access in core areas can be suitable to improve air quality.

3. ***Policy Literature within Transportation Sciences:*** Though this deliverable does not present a review of the literature that describes a range of policies that are currently

emphasized by mobility planners and practitioner communities. it has been suggested in the literature that focus is now shifted towards such policies that are easy in implementation and does not require significant investments and additional infrastructure. Owing to this, in addition to what has been recommended in deliverable 1.3 and 1.1, policies such as Telecommuting, flexible working hours and opening times of activity locations are also required to be considered. Therefore, guidelines about their implementation within the simulator and also some results from the implementation of telecommuting is demonstrated in this deliverable.

4. *Simulator Limitations:* Although a wide variety of interventions/policies can be assessed from the developed simulator, it should be noted that models always have some limitations. Mobility-related policies which are in the domain of logistics and freight transport cannot be directly tested/explored from the simulator. For example, some improvements in supply chain procedures can optimize the movements of freight traffic on the road network, which in turn reduce VKT of freight traffic and can result in lesser emissions. To test such policies, the simulator needs to be extended in a way that it can model the supply chain decisions of a particular region. Currently, heavy vehicles movements on the road network are exogenous in the integrated model.

Sub-sections 5.3 to 5.9 presents different selected policies based on the above-mentioned points. Some policies are implemented within the integrated simulator. The obtained aggregate results are shown for demonstration purpose. For all policies that are discussed in these sub-sections, methodological guidelines are discussed about ways to implement them in the simulator.

5.3 Enhancement of Public Transport Infrastructure

This is a very relevant policy in relation to ease congestion on the road network by attracting individuals towards the use of public transport instead of choosing to drive their own private vehicle on the road [*Fellermann, 2015*]. This has also been considered as a set of policies with fruitful impacts on increasing physical activity level of individuals (as individuals may walk to or from bus stops to their final activity destination). As individuals may be attracted towards this mode, there may be a smaller number of cars on the road and hence a reduction in pollutant emissions. This may thus beneficial to air quality of the city as well. Public transport can be enhanced in various ways, which are listed in the following:

1) Increase in the frequency of buses/trams for viable routes
2) Provide dedicated bus lanes, so that they can move faster
3) increasing the reliability of the Public transport through the IT-based infrastructure, just on-time concept to reduce unnecessary waiting times
4) New Public transport routes
5) Introduction of buses/trams with large capacity

Based on the description provided regarding the ABM and integration of FEATHERS + MATSIM, here we describe how this policy can be implemented in these models for assessing its impacts. The key change in the modelling system is emphasized by the italic text.

- **Increase in Frequency:** This is implemented by introducing more buses for viable routes with high demand. The impact on the individuals is that their waiting time is reduced. Often individuals consider/perceive waiting time high compared to the in-vehicle travel time due to the discomfort if offers. Therefore, the decrease in waiting time may attract some individuals towards public transport. The increase in the frequency of buses may

be time-dependent or permanent. The policy can be executed by making the following changes in the modelling system.

- o *Change in skim matrices which is the prime input for ABM (choice of mode, choice of destination, choice of time-of-day may be affected here). Skim matrices contain travel time (total or its various components) for each mode of travel between all TAZ. The task here is to identify which TAZ will be affected by this change in infrastructure, and how much total travel time or waiting time will be reduced. This can be done by running the MATSIM with new fleet (added fleet) and find out the changes in travel times and waiting times and developing the new skim matrices to work out the demand. The whole system needs to be run for few iterations so that it can provide consistent results.* The introduction of new buses to increase frequency may result in the following:
  - ▪ Car share may drop and Public transport share may increase.
  - ▪ As fewer private vehicles are on the road, congestion situations on the road may be reduced especially in peak times.
  - ▪ Individual's activity patterns may have changed, i.e. individual choosing bus transportation mode have reduced flexibility and may directly return to home. Thus, to participate further to other activities, they may use car. So, while on one hand, this policy may reduce the demand for car in peak times, on the other hand it causes higher car demands in off-peak times. Results from the simulation need to be investigated in more details to find out possible pros and cons of this policy.

- • **Dedicated bus lanes:** Dedicated bus lanes are reserved lanes for buses only on the road to facilitate smooth and fast movement of buses. Their effect is an overall reduction in the travel time between the bus stops, therefore, commuters travel time between the specific stops will be reduced as well. *It is also related to changes in the skim matrices. MATISM needs to be run with more detailed data of the road network, where information about lanes-mode is defined as well i.e. for each lane of the road modes that are allowed on those lanes are defined.* So, whichever road is envisaged with the dedicated bus lane, the input data needs to be changed as well. It may have similar effects/impacts as previously discussed for the policy of frequency change.

- • **Reliability of Public transport**: This concept is rather new, and modelled only in demand side i.e. FEATHERS. The idea is to monitor the movement of buses/trams in such a way that it ensures just in time service (buses are following their scheduled time) to facilitate commuters. *In FEATHERS, within the mode choice model, there is a variable introduced with 4 reliability levels in terms of percentiles (i.e. 50, 70 90 and 95, which could be interpreted as 50% of the time bus will follow the schedule travel time). Skim matrices contain this information for each TAZ combination based on some realistic data (as MATSIM currently is not capable to provide this information).* Decisions about choosing a Public transport may be affected by changing the values of the reliability between some TAZ in FEATHERS and once individual has decided about mode choice, the subsequent decisions may change as well. The effect may be similar as described above for frequency change.

- • **New Public Transport routes**: This is based on introducing new routes in the public transport network. *It requires changes in the input data (network details) for MATSIM and then running the model to obtain skim matrices. With the new skim matrices, FEATHERS needs to be run again and these two models need to be run in the cycle to obtain consistent outputs.* The skim matrices now contain some new TAZ combination which were not previously accessible by Public transport. This also causes changes in the model predictions in a similar manner to what mentioned for the frequency change.

- **Large capacity buses/trams:** The effect of this intervention is similar to waiting time as the introduction of large capacity buses means facilitating more individuals waiting to board bus/trams. Therefore, readers may refer back to the first bullet item in this section to understand what kind of changes needs to be implemented in the modelling system to test this policy/intervention.

As an example illustration, a policy is implemented in the simulator by increasing the frequency of direct train service between the two cities/towns in the Flanders region. i.e. Hasselt and St.Truiden. The in-vehicle travel time is around 25 minutes. Currently, this direct train runs once in an hour and there are other Bus routes which facilitate the two cities/towns with the in-vehicle travel time of around 50 mins. The policy is to introduce the direct train twice in an hour i.e. increasing the frequency. It requires huge resources in terms of arranging locomotives, train carts and additional staffs which need to be compared with the overall advantages this policy can offer. First, MATSIM simulation has run with the additional fleet in the system as mentioned above. This mainly results in changes in the waiting times. An overall avg. travel time (including waiting times, access time, egress time and in-vehicle travel time) during the peak period between the cities is estimated around 50 mins by train. Compared to the base scenario it has a reduction of 15 minutes in the avg. overall travel time by train. This causes changes in the demand, as some individual switch from car to Train. The car travel time in the based scenario was around 30 minutes during the peak times. Changes in mode shares of the trips from Hasselt to St.Truiden are presented in figure 10. It can be seen from the results that mode share of car and train are significantly changed for the trips from Hasselt to St. Truiden. More specific results could also be analysed e.g. to see which type of individuals have shifted from car to Train. In terms of the overall network the results are not that significant, however, due to this policy, part of the major road that serves the two towns have significantly low traffic and because of this, travel time by car is also reduced by 5 min during peak times. This is shown in figure 11. The policy is therefore effective in terms of decreasing the traffic volume on the road and it may therefore help in decreasing the emissions from private vehicles.
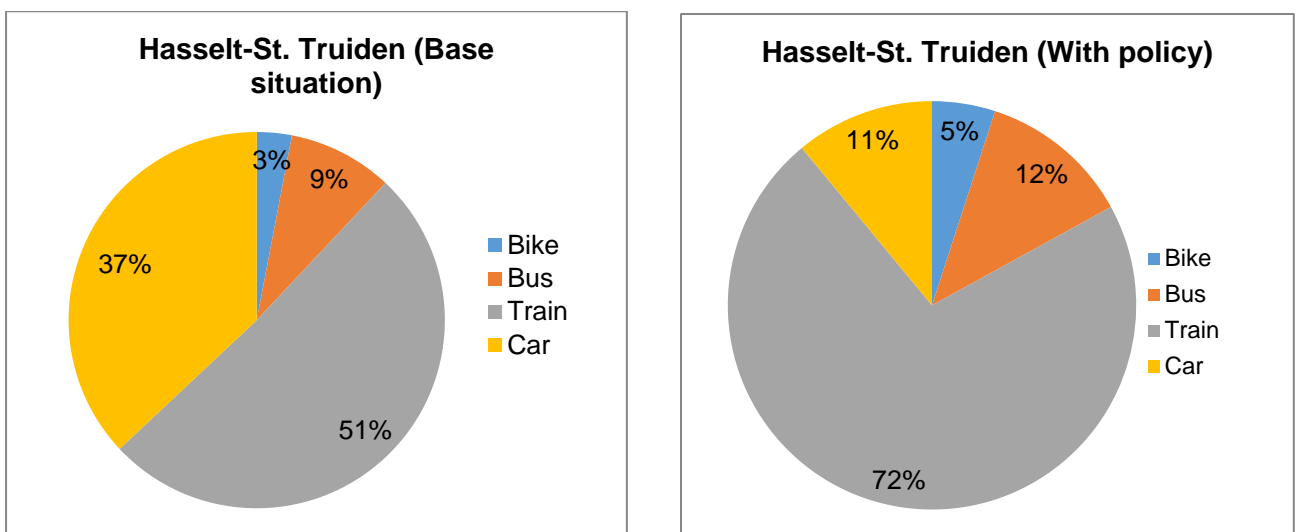

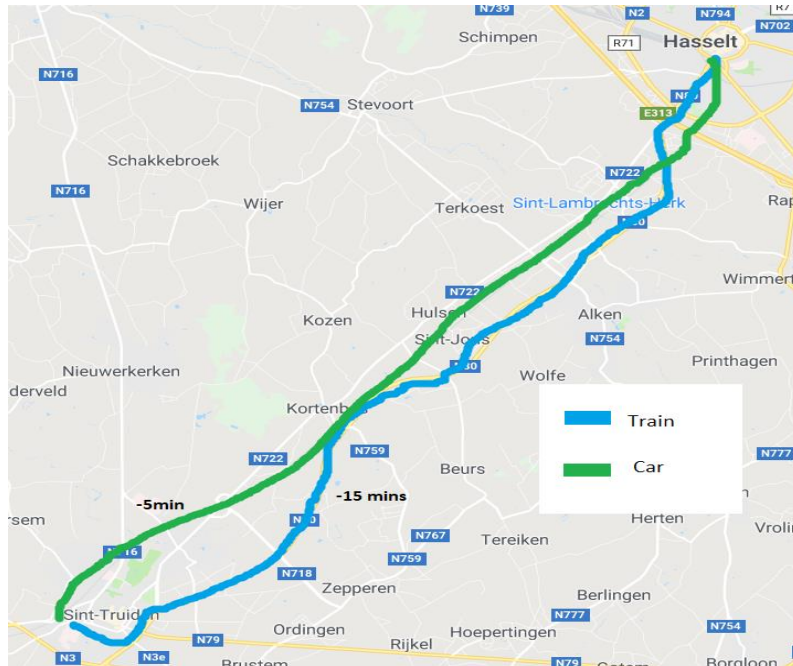*Figure 10: Mode shares base and policy scenarios*

Figure 11: Travel time changes for car and train routes after implementation of policy

5.4 Reducing Public Transport Fare

This policy/intervention is also able to attract individuals towards Public transport. In certain regions, this policy was implemented by making public transport completely free; however, it was soon realised that this policy puts too much burden on the government and therefore, only fare reduction policies have been then introduced. The majority of the schemes introduced are restricted for special categories of population, like for example; low-income individuals, elderlies, school/college students etc., because it has been shown that it is easy to attract these classes of population towards public transport. Otherwise, these categories may not have other opportunities to travel for their activities than hire other forms of private vehicles (e.g., use of taxi), which is also creating congestion on the road. Sometimes this policy is introduced by reducing fares based on spatial location or in off-peak times to lower burden on public transport in peak-times such as done in Singapore [*Lovrić et al., 2016*]. In relation to iSCAPE, it may be wise to test this policy by introducing it to certain segments of population and to see whether these categories shift their mode of travel from private to public transport.

The policy may have some small complexities as it is not dependent on changing some input variables. It is required to introduce some if-then-else statements to change the input to the modelling system. For example, if public transport fares are reduced by 15% for elderly people then the information required to execute mode choice model from the skim matrices (such as public transport fare for specific OD combination) may need to be changed in going to specific section of the code and introducing the following pseudo statement;

> if agent_age > 55 years; then
>
>> OD_PT_Fare = 0.85 * OD_PT_Fare
>
> else
>
>> OD_PT_Fare = OD_PT_Fare

Similar actions need to be performed for other classes of individuals to execute the policy in the simulation process. If the policy is defined in such a way that each agent in the population can benefit of it, then it is not required to introduce such statements. The only operation required in that case is to change the specific column (that represent public transport fares) in the skim matrices by multiplying it with the respective factor.

The changes for this kind of intervention are only performed within FEATHERS. MATSIM does not have capability to introduce such policy provided that it is being fixed for mode and destination choices. The impact of such policy is therefore primarily on the mode choice and then subsequent decisions based on this as mentioned earlier in section 5.1.

5.5 Restricting Car Use in Core City Areas

It has been proven very effective in reducing air pollution and congestion from the core city areas to make such places more liveable. Usually, individuals may park their vehicles outside the core city areas and use other sustainable transport modes such as public transport, bicycle or walk to access these areas. Some alternatives of these policies are to restrict heavy vehicles only or restrict/ban vehicles with fuelled engines [*Boogaard et al., 2012*]. The policy is complex to introduce within the model as it requires additional information and construction of new variables within the model to assess their impact. This is explained in the next paragraph.

The policy can be implemented by increasing the vehicle type column in the network details (i.e. which type of vehicles are allowed on a particular road) and also enriching details about vehicle ownership in population data (i.e. adding the fuel or car type along with car ownership). In order to enrich population data, distribution of such cars which are restricted to enter in the study area or part of the study area are required. The destination choice model within FEATHERS is then required to be recalibrated in a manner that individuals owning restricted vehicles cannot choose activities located within restricted areas. MATSIM model also needs to be run with new network details information, to bring the change in route choices because certain vehicle has to be detour as they cannot take direct route because of the restriction. Because of this change, the situation within the restricted region may be better in terms of reduction in congestion and also improvement of air quality.

Figure 12,13 and 14 illustrate few results of a case study being examined using a similar simulator as presented in this deliverable. The results reported here are just for illustration, so that reader can understand the capabilities of the simulator. The author of this deliverable is also a part of the study that has been conducted for Singapore in 2016. The intervention is devised as such that in a central region of Singapore car access is completely restricted (see figure 4(a)) and only autonomous mobility on demand (AMoD) (a fleet of autonomous vehicles that can serve a passenger on request and runs either on electricity or other clean fuel sources), public transport, taxi and walk are allowed as a mode of travel within the region. Through this case study, different impacts of such a policy are analysed for example how much fleet of autonomous vehicle is required if average waiting time for the passenger is considered to be 5 minutes, what would be the mode shares within the modelled region (green area) with and without AMoD (See figure 4 (c)) and what would be the effect on route choices for through traffic (without such policy commuters are passing through the restricted region, however with such policy, commutes need to detour to reach to their destination (See figure (b)). These results are taken from [Azevedo et al., 2016]. The results clearly indicate that the road network in the green region is only occupied by either AMOD fleet, taxi and public transport vehicles. The policy has a great potential in improving the air quality of the region.
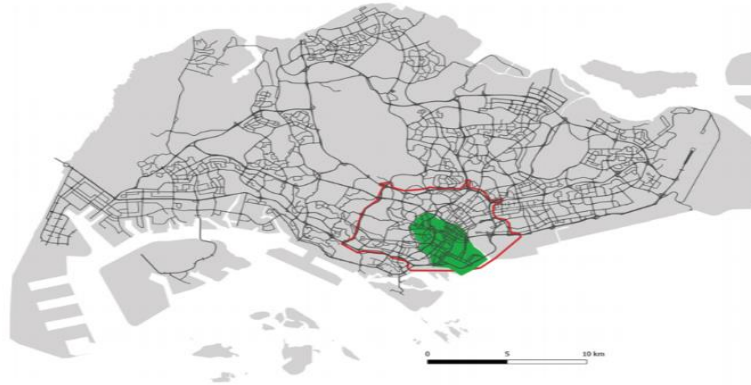
Figure 12: Singapore network and Car restricted area with AMOD system (in green)

Path	Length	Travel Time	Split
1	10.6 km	17 min	13.0%
2	10.1 km	14 min	32.4%

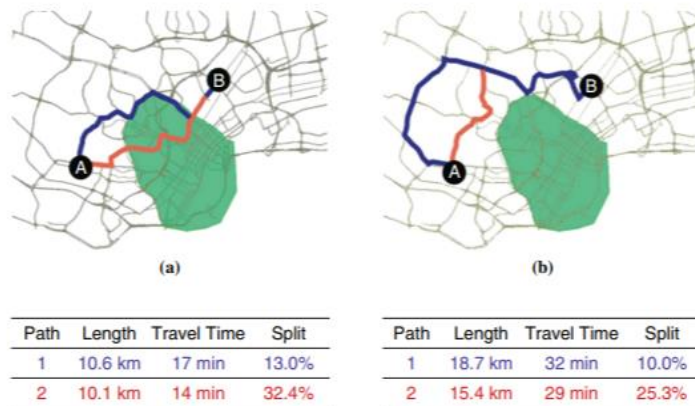| Path	Length	Travel Time	Split
1	18.7 km	32 min	10.0%
2	15.4 km	29 min	25.3%

Figure 13: Effect on through traffic, path attributes for two most selected paths from A to B without (a) and with (b) car-restricted with AMOD
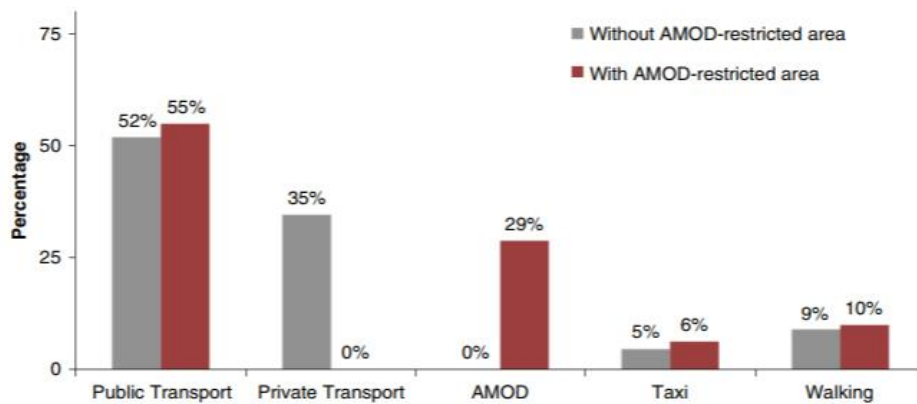

Figure 14: Singapore case study - Effect on Mode choice

5.6 Road Pricing

This policy is similar to restricting car use in some areas but instead of complete banning, it considers to charge private vehicles with some prices to regulate congestion in the core city areas, which also helps in reducing air pollution. Such policy is being implemented in many cities across the world and is subjected to detailed research on various aspects of its implementation including primarily the amount to be charged from each vehicle entering the zone. More details on this can be read from *Schuitema* [*2007*] and [*Ubbels and de Jong, 2009*].

The policy can be implemented within MATSIM and FEATHERS models. Within MATSIM the route choice cost function needs to be based on travel time and travel cost together. So the model requires to know which links of the road are priced. MATSIM runs with these changes in the network details (link which are priced with their amount priced) will provide the new skim matrices that also contains revised cost of travelling between the TAZ with private vehicles. This may entail changes in the mode choice, destination choice and activity participation choice and time-of-day choices when FEATHERS will run with the new skim matrices. Again, the cycle needs to be run few times to reach consistent results.

5.7 Flexible working Hours and Telecommuting

The intervention mainly refers to employees who work. Flexible working hours refer to the strategy where employees are allowed to start work a little bit late or end work a bit earlier to avoid travelling in peak hours. Telecommuting refers to the strategy where employees are allowed to work from home for a day or two in the week. The effects of these policies are relatively small in relation to congestion and air pollution reduction [Kim, 2017].

This can be implemented in the FEATHERS model where time-of-day decisions are taken. This model may need to re-calibrate with the additional variable for the agent, whether he is available with the kind of work that offer flexible working hours. This information needs to be added into the population details data based on some assumed distribution based on the policy. Similarly, those individuals who are employed in a working condition that can offer telework needs to identified using certain assumption within the population. The model for choose number of work episodes needs to be recalibrated with a new variable that is available in the changed population. No action will be required to change the MATSIM model as this is mainly a demand side policy.

As an example illustration, the telecommuting policy is implemented for the population of the entire Flanders region. The assumptions considered in the model is that 5% of the workers are available with telecommute option. This characteristic of a worker is entered in the population data. It is not necessary that all agents available with the telecommute option may choose this option on a certain day of simulation. It is based on the model outputs. FEATHERS contains a DT (i.e. choose the number of work episodes) which have a discrete variable in the form of 1 and 0 (indicating whether an individual has a telework option) along with other variables. The model can simulate an output if the worker decides to choose an outcome related to telecommuting. Furthermore, the decision of this top-level model goes into lower level models as well that may affect other decisions of individual activity pattern. Some aggregated outputs are shown here to describe the effect of such policy when the simulation is performed for seven days of the week separately. Table 3 presents the impact of the policy in terms of Vehicle kilometers travelled (VKT) for each day of the simulation run for base and policy scenario. VKT represents aggregated total kilometers all vehicles have traversed in the road network. In table 3, it is found to be lower for working days (Monday to Friday) of the week in relation to weekend days (Saturday and Sunday). During the weekend days, the differences in VKT is mostly due to the randomness incorporated within the whole modelling system. In the literature, this is often

called as microsimulation error. Therefore, it can be said that policy may have some impact on the reduction of emissions from the vehicles. Figure 15 represents the result of the policy scenario by showing the reduction extent of VKT by gender for both type of workers (i.e. workers commute to workplace and telecommuters). It can be easily seen in Figure 15 that those who telecommute on a given day have significantly lesser avg. VKT by car compared to those who commute to their workplace. In general male have higher avg. VKT per day by car compared to females. There are a variety of other ways in which impact of this policy can be presented from the outputs of the simulation i.e. by interacting changes in VKT by socio-economic variables or by showing differences in the network volumes on major roads during the peak times.

Day	Base scenario VKT (10^9)	Telecommuting VKT (10^9)	Difference
Mon	0.137	0.134	-1.96 %
Tue	0.141	0.138	-1.89 %
Wed	0.135	0.132	-2.16 %
Thu	0.138	0.135	-2.11 %
Fri	0.136	0.134	-1.96 %
Sat	0.119	0.119	-0.15 %
Sun	0.102	0.102	-0.11 %

Table 3: VKT in base and telecommuting scenario for each day of the
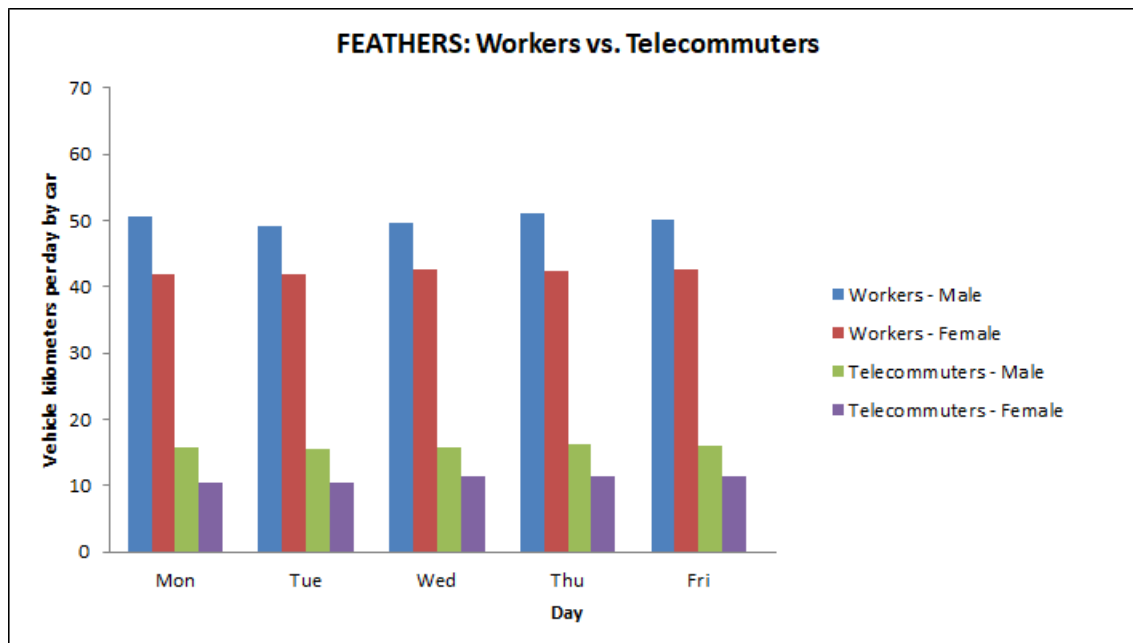

Figure 15: VKM travelled per day by car for workers and telecommuters

5.8 Policies related to opening/ending timings

The policy is mainly related to stores and school opening and ending times. Changes in these times may result in changing schedules of individuals in a variety of ways i.e. participation in activities, mode, destination, time-of-day choices for activity participations. MATSIM and FEATHERS both can be activated for this kind of policy.

Activity participation utility scoring function parameters can be changed within MATSIM to execute this policy. For each and every considered activity, it is required to define the earliest and latest possible times. For example, for school/education and school escorting activity certain strict criteria for opening times can be considered after morning peak times or before morning peak times. The effect could be to change time dimensions of the school/education activity and also on school escorting activity within MATSIM. However, the change in this may cause changes in Skim matrices and an indirect effect of this on the scheduling dimensions considered within FEATHERS can be obtained on the activity schedules of individuals.

5.9 Parking Regulations

Parking regulations can be key to manage urban traffic. There are a variety of ways in which these regulations can be implemented. For example, increase in parking charges (Parking fee) in core city areas, reduction on number of parking spaces, strict monitoring of parking officers etc. In relation to the behavioural simulator, it can consider regulations based on pricing strategies such as parking fee to consider another element within the travel cost.

The policy is mainly a demand side policy by considering the increase in cost between the combination of ODs. The overall cost now includes parking charges as well. It could be an extra item within the skim matrices and it can be included as total cost of travel between the two TAZ or OD. Main sub-models that will be affected is the mode choice and destination choice models within FEATHERS.

As an example illustration, the policy is being implemented in FEATHERS_+ MATSIM and the output results are shown on the map (see figure 16 and 17). The study area is a small region of the Antwerp city, which is representing a part of the city centre and enclosing many shopping streets, museums, restaurants and a leisure area by the Scheldt river (figure 16). For simplification of analysis results, a policy is implemented in the simulator in a way that for all streets within the study area no parking fee is charged. Within FEATHERS, for all the destination within this region travel cost in the skim matrices is changed by reducing the parking fee to zero. Saturday is simulated using MATSIM and the results are shown by compiling the MATSIM outputs. Figure 16 presents aggregated results in terms of the number of cars that have their destination on a particular street of the region (we assumed that cars destined on a particular link are parked on the same street). The streets are considered to have h a definite number of parking spaces. As soon as all parking space occupied on a particular street, cars are assigned to the next close street where parking space is available. The reported results showing the parking demand for the time period of 1100hrs-1200 hrs. The labels in the figure show % occupancy of the street by parked vehicles. It can be seen very clearly that when parking is considered free, more vehicles are destined in the region, as parking spaces in many streets are almost filled. This indicates that more vehicles are arrived in that time period, which is the results of the individual change in the destination choice. In paid parking situation, some individuals have not chosen this region as their destination for a particular activity.
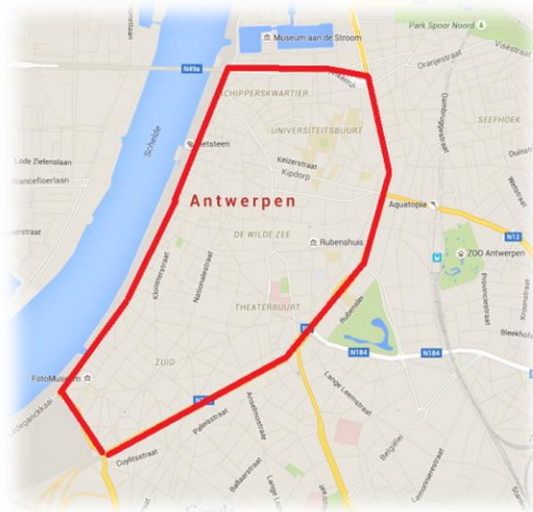
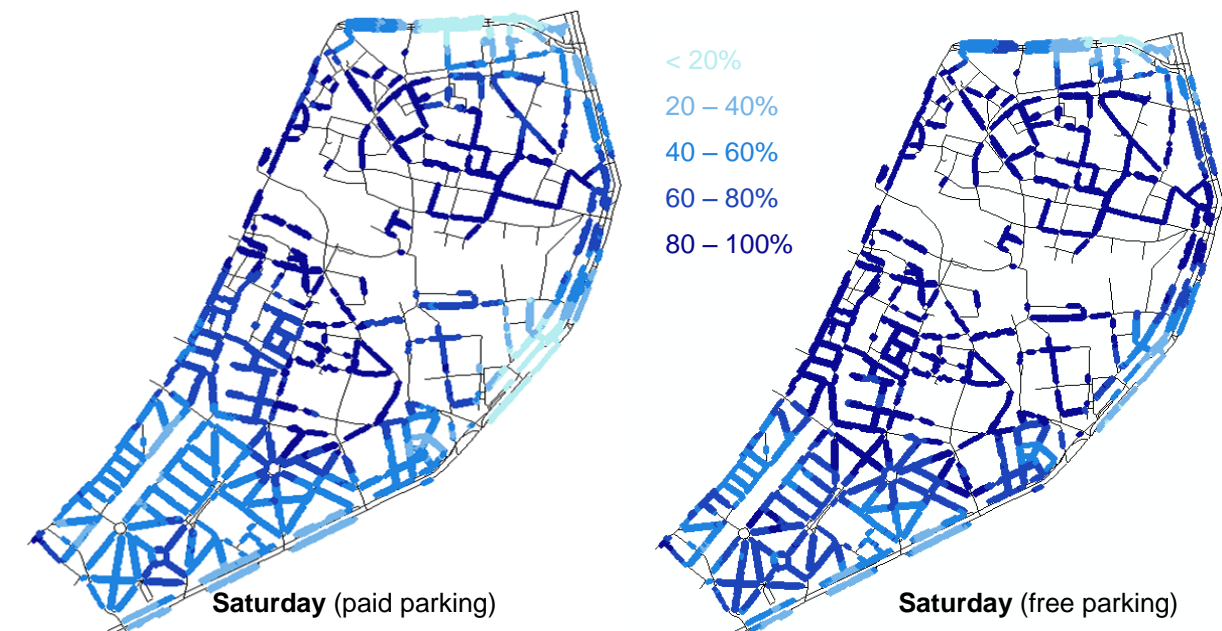*Figure 16: Study area in Antwerp with no parking fee at the streets*

< 20%

20 – 40%

40 – 60%

60 – 80%

80 – 100%

Saturday (paid parking) **Saturday** (free parking)

Figure 17: Map representing %occupancy of parking space in the streets for paid and no parking fee

6 Conclusions and Way Forward

6.1 Conclusions

The section concludes the discussion presented in section 3 to section 5. The key conclusions are as follows:

- FEATHERS as an activity-based model provide the required outputs so that it can be easily integrated with MATSIM for executing the generated plans in the road network.

The cost/utility function within these models are such that they can handle a variety of policies/interventions. For implementing such policies, mainly input data (such as skim matrices, population, land use data) needs to be adapted to reflect policy scenarios.

- The integrated model that combines FEATHERS with MATSIM, which is developed for Flanders region is well calibrated as the outputs of the simulation are validated against the traffic counts collected over 400 locations within the Flanders region. However, it should also be considered that if other datasets are available such as regional OD matrix, simulation outputs should also be validated to develop more trust in the model results, especially when it is used for policy analysis.

- Criteria for selection of TDMs is reasonably sound as it provides policies/interventions that are more effective in relation with air quality improvement. However, at the same time, it provides policy measures which are cost effective and easy to implement, though these policies are not as effective as TEZ and policies that promotes public transport.

- Results of the policies that are implemented within the developed simulation tool, such as increasing the frequency of the train between two towns, Telecommuting and no parking fee are found plausible and provide meaningful insights into the effects of such policies in reducing emissions from cars. Furthermore, simulation outputs are comprehensive and outputs can be compiled in various ways to develop the holistic picture of the particular policy.

6.2 Way Forward

The following are key recommendations for further steps in WP 4.

- This deliverable should be read by all partners leading living labs in iSCAPE cities. The document not only provides the overview of the behavioural simulator but also provide the potential policies, some of which may be relevant to a particular city. Based on the results of some policies that are demonstrated in this document, relevant city representatives can be approached to define a particular scenario in each city that can be executed in the light version of the simulator for its impact assessments if other required datasets are available from iSCAPE cities. **This is relevant for task 4.2.2 of WP 4.** In the case of Hasselt, this deliberation is already made with city stakeholder, based on which policy related to telecommuting and increase frequency of train are analysed. Some results of these policies are already described in this deliverable.

- Results of some selected policies implemented considering Hasselt city may be embedded into another chain of models i.e. emission and air quality dispersion model, so that impacts of these policies can be assessed on air quality. **This is relevant for task 4.3 of WP 4, where air quality model will be run for some selected policies in selected cities depending on the other required data availability.**

- In relation to measured pollutant concentration maps for a particular policy scenario (as an output of air quality model) exposure of individuals in terms of their socio-economic characteristics may also be analysed to identify vulnerable groups within the population and these outputs can be further used for assessment of health impacts. **This is relevant for task 7.3 of WP 7.**

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