SIMULATING DAILY MOBILITY IN LUXEMBOURG USING MULTI-AGENT BASED SYSTEM

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ABSTRACT

This paper describes a daily mobility model which allows realizing urban simulation to help understanding future land use management policies. The main challenge in such urban simulation consists of how to evaluate future situations since where comparison with real data cannot be possible. The work presented in this paper is about solving this problem and encouraging results have been obtained. Experiments have been made within different scenarios in Luxembourg.

INTRODUCTION

Luxembourg emerges as a very attractive cross-border regional metropolis leading to increasing residential migration and longer commutes. Empirical evidence shows that current urbanisation trends toward suburban and more remote per urban areas favour urban sprawl and car dependence. Urban sprawl is a very important territorial challenge to be addressed by policy makers since it is often associated with overconsumption of land and energy, fragmentation of natural habitats, difficulties in the provision of public services and increased residential segregation.

Further understanding social, economic and environmental impacts of both the residential mobility and the daily mobility of households is the core of this work. The MOEBIUS project relies on a solid knowledge base of interactions between daily and residential mobility acquired by the CEPS/INSTEAD, especially within the MOBILLUX project (Gerber, 2008). Within this work, we aim at developing an approach in order to simulate the future daily mobility (commuting patterns and travel mode choice) for different land use planning scenarios. When assessing those scenarios, particular attention is put on how they can provide a good trade-off between, on the one hand, economic growth via the provision of attractive and affordable living places, and, on the other hand, environmental, economic and social sustainability (modal split, land take, land rent, accessibility).

Using mathematical modelling and urban simulation can be applied on different domains such as transportation capacity, transportation system management, transportation demand management, land use/growth management policies economic development policies and environmental policies. A good work for the introduction of urban simulation can be found in (Paul & Gudmundur, 2004). The origin of the application of computer simulation techniques for urban problems dates back to the 50s (E. Klosterman , 1994). Nowadays, the urban simulators are able to support the monitoring development as well as the objectives of the growth management acts. The MOEBIUS project is orientated towards a simulation of interactions between residential and daily mobility's for better understanding urban sprawl in Luxembourg and testing prospective planning scenarios. Given the complexity of the whole urban system (in particular the cross-border setting) and of these interactions, MOEBIUS is focused on the residential and daily mobility of the active population, i.e. workers employed in the Grand-Duchy and living inside the country.

METHODOLOGY AND APPROACH

Nowadays, simulations based on Multi-Agent Systems (MAS) are used in a growing number of sectors, where it is gradually replacing the various techniques of micro simulation and object-oriented simulation. This is due, in part, to its ability to capture very different styles of individuals, from very simple to more complex entities (as cognitive agents). The ease with which different levels of representation can be handled by the modeller is also one of its qualities comparing to the cellular automate. This apparent versatility makes MAS the medium of choice for the simulation of complex systems and spreads in an increasing number of domains: sociology, biology, physics, chemistry, ecology, economy, etc...

Simulation in Transportation Systems

Within the transport simulation, a list of extendible questions has to be taken into account: the vehicles movement, delays at crosswalks, time-dependence, and the itinerary that he agent will take, etc.

MATSim: a Multi-Agent Transport Simulator

MATSim is an open source multi-agent based transport simulation tool which was initially developed from the TRANSIMS project (Smith, Beckman, Anson, & Nagel, 1995) MATSim offers a framework for demand-modelling, agent-based mobility-simulation (traffic own simulation), re-planning, a controller to iteratively run simulations as well as methods to analyse the output

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generated by the modules[1]. MATSim represents each entity from the physical world (person, car ...) by an individual agent. The approach is mainly described by the following three concepts:

- The activity-day of an agent is described by a so-called plan. Iteratively, an agent tries to optimise his plan, by changing its intentions (leaving time, itinerary ...).
- The mobility simulation, which consists of the concurrently execution of the agent plans respecting limits set by the physics of the reality (speed limits, low capacity of roads, position of other roads, direction of roads, vehicle capacity, open time ...)
- Learning concept, which is responsible for making improvements of the agent choices. The system iterates between plans generation and mobility simulation. A function score is used to evaluate the performance of a plan.

Problem formulation

Specifically the problem we aim to solve, in this paper, is to design a platform around the MATSim simulator which will help to study and analyse the residential mobility across different scenarios. The objective is to measure the consequence of decisions, related to future developments, on citizen's mobility. This platform (with specific configurations is called "Daily Mobility Model" (see Figure 1).

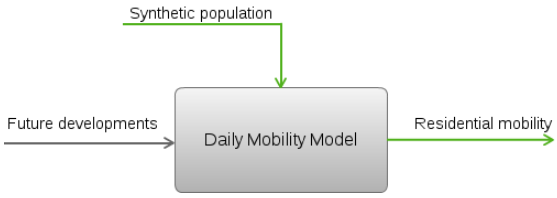

Figure 1: General Process

The daily mobility model is based on the modelling of route choice and mode choice for the journey to work. This includes (i) the agent specifications (i.e. age, type of household, car ownership...), (ii) the environmental characteristics (e.g. transportation networks, local densities at origin/home and destination/work), (iii) a decision tree (a set behavioural rules) obtained from a database describing mobility behaviours and used to simulate the mode choice. The behaviour of the agents will be controlled by MATSim, including interactions between agents like communication, and learning based on the previous route choices. The simulation of route choice will consist of executing the "best path".

By scenario we mean, firstly, a strategic tool for choosing between different possibilities of development and, secondly, a tool for the coordination of sectorial plans as well as a framework for planning at the regional and communal levels. The scenarios will primarily vary the location of expandable land (according to accessibility measures) and threshold densities (within a raster GIS). In addition we may vary workplace clusters considering specific development projects.

A synthetic population may be defined as an artificial population composed of individuals with associated individual characteristics (level n), and constructed from known at the aggregate level (n+1) census data. This population is called "synthetic" because it is reconstructed using conditional probabilities and assignment algorithms. It considers each individual person as an "agent" by exceeding the aggregate data provided by the statistics. These agents, whose characteristics are deduced from the general census of the population, are grouped into households, these households, whose number and size are aligned on demographics, "retrieve" additional features that emerge from individual agents (this is particularly the case for household income, calculated from the occupational category of individuals who compose it). In this work, the synthetic population of Luxembourg has been constructed based on demographic perspectives (time horizon 2020) and available households' surveys at a spatially disaggregated level. Barthelemy and Cornelisi (Barthelemy & Cornelis, 2012) explain the most known synthetic population generation methods.

THE DAILY MOBILITY MODEL

The approach that we propose in this paper, is defined on two steps. The objective of the first step is to validate the configuration of the MATSim simulator with real data, this step is called the t0 (stage of validation). By t_0 we mean the current situation regarding infrastructure and residential place of the synthetic population. MATSim will require several configuration parameters to get accurate results, for this reason we consider the t_0 as a capital phase. Indeed, this step consists of configuring the simulator, and then validates this configurations with a simulation using real data. The validation of this simulation is possible through real data based on the results of the cross-border transport survey held in 2003 by CEPS/INSTEAD. The configuration step will be repeated until the validation conditions are meet.

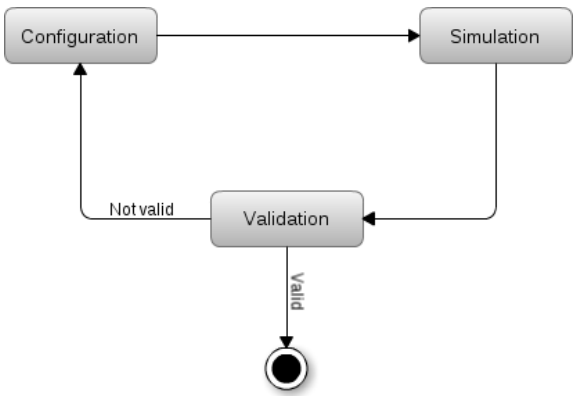

Figure 2: The processing steps of the t_0 stage

The second step consists of making the main simulations of the different scenarios. Since the configuration steps is performed, we assume that the

[1] http://www.matsim.org/

model is now able to provide realistic simulation based on the input data of the simulated scenarios and the configuration parameters resulting from the first step.
We call this second step t_1 (stage of execution). In MATSim, the result of a simulation is a set of events, which are used to document changes in the state of an object (agents, vehicle, arc, edge ...). This list of events is then used in the post-processing step in order to analyse the simulation and create the output of the daily mobility model. The output put of the model will be discussed below.

The validation stage: t_0

Every simulation is based on a theory, namely a set of postulates, laws, principles, theorems ... to build a model from data and initial assumptions then used to produce the outcome. In our case, the theory (traffic rules and law, planning, etc. …) is provided by MATSim and data are the synthetic population and the infrastructure oft_0. The main configurations of the MATSim simulator are carried out through the configuration input file. Following are values of the parameters that we have configured within this stage.

MobSim
MobSim is the execution module of the agents' plans, several MobSims have been developed, some of them are still in use, and others are obsolete[2]. The MobSim we have used in this work is the QSim, which is a queue model time step approach using a deterministic algorithm[3]. The QSim is an extended version of the QueueSimulation. Features like traffic signals, within-day and public transport are available with the QSim implementation.

Replanning Rates
The replanning is an important step on the MATSim iterative processing; it consists of changing the behaviour of the agent in order to optimize his day plan execution. This change can affect his itinerary by choosing a new route or he structures his current plan (e.g. the start and end-time of an activity), sometime the agent keep the same plan for the next iteration. A replanning module is a component which applies a specific strategy to adapt the agent plan. Within MATSim it's possible to develop (modify) a personal module and some default replanning modules are available. Different modules can be used within the same simulation, in such situation the agent will choose one module randomly based on a configuration parameter.
The figure 5 presents the configurations of the strategy module that we chose. Each probability module is defined by two parameters. The first one specifies the name of the module. And the second one defines the probability that the strategy will be adopted by the agent. After a manual optimization step we have set the configuration values as following:

- BestScore: This module will select the plan which has the best score from the existing plans of the agent. This module has 80% of chance to be selected
- ReRoute: Try to find a new optimal route by calculating a new one using the default routing algorithm, travel times are selected from the previous iteration. This module has 10% chance of being selected
- TimeAllocationMutator: Changes randomly times of the agent's plan, by changing the duration of an activity within the respect of the person specification. This module has 10% chance of being selected.

```
<module name="strategy">
        <param name="maxAgentPlanMemorySize" value="5" />

        <param name="ModuleProbability_1" value="0.8" />
        <param name="Module_1" value="BestScore" />

        <param name="ModuleProbability_2" value="0.1" />
        <param name="Module_2" value="ReRoute" />

        <param name="ModuleProbability_3" value="0.1" />
        <param name="Module_3" value="TimeAllocationMutator" />
</module>
```

Figure 3: The replanning strategy con

The objective of the replanning phase is to optimize the day plan of each agent and so the system became more realistic and react accurately the behaviour of the population we want to simulate. This is due to the fact that naturally the human always try to optimize his itinerary and finally chooses the best path according to his preferences (arrival time, modes …). The diversification and the intensification are two important aspects in the field of the optimization. Diversification means the process of gathering information about the problem; this can help to discover more possible solutions. Intensification (or exploration) aims to use the information already collected to define and browse the interesting areas of the search space. The concepts of intensification and diversification are preponderant in the design of combinatorial algorithmic, which must achieve a delicate balance between these two dynamic searches. In our case, this may be controlled using the strategy module configuration. Indeed the “best score” module aims to choose the best plan according to the score function, and so it promotes the intensification. The “ReRoute" and the “TimeAllocationMutator" will try to discover new possible solutions (best day plan) by doing some minor modifications within the current plan, this can promotes the diversification.

Change Scoring Parameters
The score of a day plan is the objective function in optimization. “Objective function" is the term used to describe a function that serves as a criterion to determine the best solution to an optimization problem. Specifically, it associates a value to an instance (a solution) to an optimization problem. The goal of the

[2] more details can be found in: An Overview of the MobSim; http://matsim.org/node/619
[3] A deterministic algorithm is an algorithm that at each step always go to the next step in the same way

optimization problem is then to minimize or maximize this function until the optimum.
The principle of the scoring function of MATSim is described in detail in (Charypar & Nagel., 2005). The Figure 4 describes the parameters that we used to configure MATSim scoring function for the t_0 stage. The signification of those parameters is the following:

- **lateArrival** : Decrease the score by 18 units if the agent arrives late to his last activity (work in our case)
- **earlyDeparture**: No influence on the score if the agent starts his route early. It can be logic if it's the only way to respect his arrival time
- **performing**: Increase the score by 6 units if the agent arrives to the last activity with respecting all the time constraints. In our case the departure time from home and the arrival time to work.
- **traveling**: Decrease the score time of plan when the agent is traveling. This encourages the agent to arrive as soon as possible.
- **waiting**: No problem if the agent needs to wait.

```
<module name="planCalcScore">
        <param name="learningRate" value="1.0" />
        <param name="BrainExpBeta" value="2.0" />

        <param name="lateArrival" value="-18" />
        <param name="earlyDeparture" value="-0" />
        <param name="performing" value="+6" />
        <param name="traveling" value="-6" />
        <param name="waiting" value="-0" />
</module>
```

Figure 4: The scoring parameter configuration

The routing algorithm
By default, MATSim uses a routing algorithm based on Dijkstra's shortest path algorithm; however, it is also possible to use another type of algorithm. An implementation of the A* algorithm is also available with MATSim, which is a heuristic extension of the Dijkstra' algorithm known to be faster. We used the A* algorithm as a routing algorithm, this can be done with the "routingAlgorithmType" parameter of the "controller" module, see Figure 5.

```
<module name="controler">
        <param name="outputDirectory" value="&OUTBASE;" />
        <param name="firstIteration" value="0" />
        <param name="lastIteration" value="100" />
        <param name="runId" value="run0" />
        <param name="routingAlgorithmType" value="AStarLandmarks" />
        <param name="mobsim" value="qsim" />
        <param name="writePlansInterval" value="1" />
</module>
```

Figure 5: The "controller" module configuration

The t_0 input network
Within MATSim, one of the possible sources of the transport network is the OpenStreetMap[4]; indeed MATSim offers some tools to transform an OSM (OpenStreetMap) map to a MATSim network. The OSM map that we used for this stage, came from the Geofabrik's free download server[5], this server extracts data from the OpenStreetMap project which are updated every day.

The t_0 population
The synthetic population of t_0 represents the current real population, with a day home to work scenario of the Luxembourg resident. The decision to exclude the border is due to the unavailability of data and not for technical reasons. The population is initially composed by about 190.000 persons, after applying the modal choice using the decision tree, 76.9% of them choose to use the car mode. The input plans file is then composed by about 146.000 agents using their car. The time planning of activities (home, work) is as follows:

- Leaving home: The time, when the agent should live his home is randomly selected between 06h00 and 08h00.
- Starting work: An agent is expected at work between 06h00 and 10h00. This time is selected randomly according to a fixed probabilities (see experiments section)

Those values were chosen based on the result of Luxembourg transport survey held in 2003. We should also note that the plan generator takes into account the distance between the home and the work to generate the start and the arrival time, the expected itinerary should be feasible in this range of time. Despite this, some agents will not be able to respect their plans due to the congestion and then have to find an alternative (an early departure or a late arrival for instance). This choice will depend of the plan score.

The execution stage: t_1

The main simulations of the different mobility situations will be performed within this stage; this will be done by developing scenarios using official strategic planning documents to represent the promoted and the real-world visions of regional planning. For more details on the differences scenarios please refer to (Rieser, 2010).
The method for developing scenarios that articulates different sets of available lands is carried out with the use of data that can be found in usual municipal/ agglomeration governments. Its implementation is based on a Geographical Information System (GIS) where planning scenarios are built on the "interpretation" of the Luxembourg official urban planning documents combining different scales: 1) national development framework, 2) regional planning orientations, 3) sectorial development plan, and 4) local management plan for residential development.
Following the scientific literature and the review of spatial planning policies within the context of Luxembourg we identified four spatial development scenarios: 1) Inner City Development, 2) Transit Optimization Development (TOD) 3) Centers of Development and Attraction System (CDA) and, 4) Business as Usual (BaU). These scenarios are based on the dimensions derived from the scientific literature on

[4] http://www.openstreetmap.org
[5] http://download.geofabrik.de/

sustainable urban development and the specific objectives of the spatial planning visions.

The modal choice

The module of the transport mode prediction is based on the work of Omrani et al. (Omran, Charif, Gerber, & Awasthi, 2013). The objective of this module is to select a mode for an agent based on the characteristics of the person that it models. This module is based on an Evidential Neural Network (ENN). The presented model uses individuals' characteristics, information on the daily mobility, transport mode specifications and data related to places of work and residence. The results were compared by cross-validation the rates of successful prediction obtained by ENN and several alternative approaches. The results show that the ENN is superior to the studied alternatives. The outcomes of this module are a set of behaviour rules. Those rules help to build the decision tree (see an example in Figure 6, where nodes are probabilities of each mode to be selected (car, PT: public transport and others: bike, walk ...) and branches present the value of the tested attribute (distance from home to work, gender, etc.). The decision tree is then used by the plan generator to select randomly a mode to the person according to his characteristics. The generator will determinate the node in which the person belongs and so the probabilities of each mode. Finally the returned mode will be selected according to this probability.

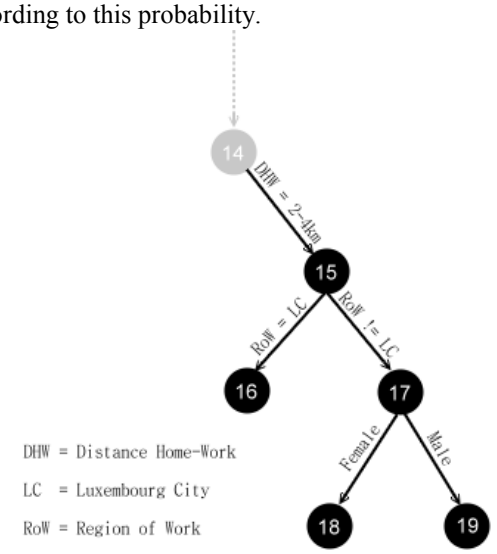

Figure 6: A part of the modal decision tree. (Probabilities is as following: Node 16: 73% car, 10% PT, 17% others. Node 18: 70% car, 13% PT, 17% others Node 19: 72% car, 11% PT, 17% others)

Future developments

In order to simulate the future daily mobility with different land use scenarios, we should take into account the future urban developments. Otherwise it's not accurate to test future population mobility within a current transport network. In order to consider the future planned routes we used an OpenStreetMap map which allows taking under consideration roads that are in constructions or planned in near future. This feature is available by using the “proposed" and “construction" tags. Some other tags can also be used to detail this feature, namely the date of the expected end of constructions. So, to build the future network we have used the current OpenStreetMap map of Luxembourg by changing all roads that are under construction (or planned) to be considered as in-use. Only constructions that are expected before 2020 have been integrated. The obtained network (t_1) is composed by more than 450 new links and 200 nodes.

EVALUATION OF SIMULATION RESULATS

The daily mobility model proposed in this work is organized in two phases. The aim of the first is to configure the simulator and to validate these configurations within a real data. This first stage is very consequential on the reliability of the simulation results within the second stage. In the previous section we have presented the configurations approved in the first stage. In the next paragraph we will present the simulation results in terms of traffic analyses and comparison with the real situation. Since the objective of this stage is only the configurations of the model, no discussion on the simulation performance will be presented. This work will only focus on the agents' behaviours to compare with the real case.

Results of stage t_0

The simulation was performed until meeting the optimum, which means stability on the variation of the score agents (after 30 iterations). The simulator output was then analysed to deduct, for each agent, the executed route plan in the last iteration (the optimal) and therefore its itinerary, departure time, arrival time and the transport mode (necessarily the car in our case). Next, these results were crossed with geographic data to determine the time spent by agents to travel from a given residential commune to work place. Table 1 presents a comparison between times obtained by the model and real times resulting from surveys. The table presents the mean, median, minimum and maximum time to travel from a home region to the different work regions. The chart presented by the Figure 7 resumes the results of the previous table by giving the error rates of obtained times relative to real times.

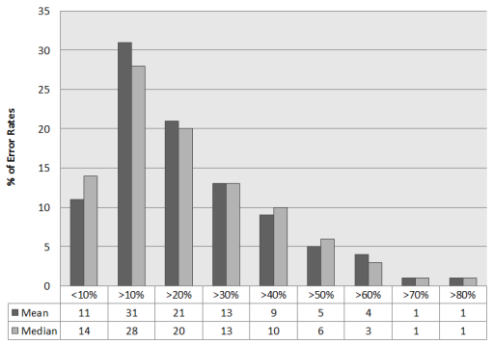

Figure 7: Error rate of mean and median simulated times relative to real times fort_0.

Table 1 The results of the t_0 Simulation: comparing the agent travel time with real times

Regions		MATSim Simulation Results				Survey Times			
Home	Work	Mean	Median	Min	Max	Mean	Median	Min	Max
North-Center	Basse Alzette	**8,21**	8.0	0	30	**11.46**	10	2	30
North-Center	Center	**28,14**	28	3	60	**29.94**	30	10	90
North-Center	Moselle	**27.8**	28	5	60	**29.7**	26	15	60
North-Center	Oesling	**21.79**	21	2	57	**21.54**	20	10	35
North-Center	South	**42.06**	42	20	191	**48.57**	40	40	90
North-Center	Luxembourg City	**33.15**	33	12	61	**34.02**	35	1	60

Results of stage t1

First the table 2 presents the modal distribution according to the different used scenarios. As the population is quite different from one scenario to another, the modal distribution is neither the same, as it can be seen in table 2. This modal distribution directly affects the number of agents that will take part to the simulation (only persons taking their car are represented). Those scenarios have been simulated separately by running the same simulator environment (configurations outcome from the first stage) within specific agents (representing the input scenario) at each run, as described in Figure 3. So, for simplicity and without loss of generality, to analyse the MATSim output simulation results, we will take the "Business as Usual" scenario as an example.

Table 2: Modal distribution of the different scenarios

Scenario	Car(%)	PT(%)	Others(%)	Agents(car)
Inner City	71.67	18.55	9.77	150849
TOD	73.76	17.97	8.25	157705
CDA/Luxembourg	76.13	17.54	6.31	159934
CDA/Belval	76.32	16.76	6.90	162354
BaU	77.36	17.06	5.56	162650

One of the important analyse offered by the MATSim controller, is the score statistics generator, which may help to follow the progress of the optimization. Figure 8 presents a chart of best, worst, average and executed plans by agents during a complete simulation (30 iterations). It is especially important to note, that the curve scores of the executed plans is stagnating within the 20-25 iterations. This finding is very important in the optimization field, because it confirms the convergence of the model. It is of course very important to ensure the convergence of an algorithm, but the speed of convergence and complexity are also factors to consider when designing or using a model. Within MATSim, the configuration step may have a strong influence on the model convergence.

Now let's focus on the behaviour of the agents in term of expected departure and arrival times. As we have explained in the configuration section, the MATSim controller will try to change the departure time of the agent if there is no way to optimize the score function, in other terms if there are many planned congestions on the taken road. We have allowed this behaviour by configuring the early departure to have no influence on the score function. However, this can conclude to inaccurate results if the number of agents that does not respect the departure time is important. First, the Table 3 gives the number (and percentage) of agents leaving the home before 06h00 and those after 08h00. This time slot has been fixed in the configuration step. More than 90% of agents respected the departure time condition.
The table presents also a comparison between the percentage of expected agents by arrival time slot (this percentage is fixed by the configurations) and times obtained by the simulation.

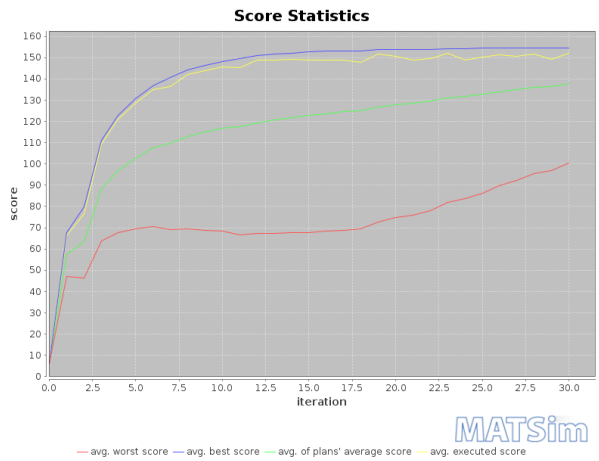

Figure 8: Statistics of the score function for the "Business as Usual" scenario simulation

CONCLUSIONS

This paper has sought to develop an operational urban simulation model called "a daily mobility model", in order to further understand the social, economic and environmental impacts of the residential mobility and the daily mobility of households, with a specific reference to the MATSim simulator. To be relevant, our challenge was the design of a model that should be able to work with future scenarios and gives reliable results. To deal with this problem, we have presented a model composed by two steps. The first one consists of a configuration process in which we have iteratively simulated the behaviour of the current population and compared the output of the model with the real data until reaching a threshold of acceptable similarity at which the model is considered reliable.

Table 3: Departures and arrivals time intervals: Expected and Simulated

	Departure Time		Arrival Time			
	Before 06:00	After 80:00	Before 06:00	06h – 08h	08h – 09h	09h – 10h
Number	3035	12496	331	116490	43188	2634
Percentage (simulated)	1.87%	7.68%	0.20%	71.62%	26.55%	1.62%
Percentage (expected)			0.00%	70%	25%	5%

The second stage defines the process of the core simulation to perform, in this paper we have presented the simulation results of several land use planning scenarios of Luxembourg. We have also presented in this paper the transport modal choice used by the agent to select their principal transport mode as well as their preferences implemented as a score function in MATSim.

The daily mobility model will be further developed to add the transport modal choice into the simulator, this will help to get a more realistic modal distribution by letting the agent choose their mode according to their benefit. Also taking into account the public transport mode is part of our upcoming perspective, this includes especially the park and ride modality which is very important within the Luxembourg context.

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AUTHOR BIOGRAPHIES

- Dr. Hedi Ayed has more than 5 years' experience in algorithm design and optimization. Following a Ph.D. in computer science he took a position as computer scientist at CRP Henri Tudor. He works in the areas of transport, intelligent systems and software engineering. His recent interests are related to traffic simulation and multi-agent systems. He is expert in the application of the optimization algorithms to problem is related to mobility. He mainly participated in several previous and current EU projects: CARLINK, MOEBIUS, STIMULATE, ELEC'TRA.
- Dr. Djamel Khadraoui received his PhD in Vision for Robotics (1996) from University Blaise Pascal (France). He is at CRP Henri Tudor since 2002 as a Program Manager of Mobility activities. He is Lead R&D Manager and active in the areas of eMobility and Critical Infrastructures Protection. His main scientific interests are: intelligent and adaptive systems, distributed systems (multi-agents systems), software engineering, trust and security in IT Infrastructures. He mainly participated and coordinated several national and EU projects. He is currently providing lectures at the master level in IT Security (Distributed Systems Security, PKI, DB security and Dependability) at the University of Luxembourg and University of Lorraine (France). He co-supervised several PhD works related to multi-agents and distributed systems, security, optimization techniques for telecommunication and multimodal transport issues.
- Benjamin Gateau received his Ph.D. in Computer Science at Ecole Nationale Superieure des Mines de Saint-Etienne in June 2007 resulting from a joint project between the CRP Henri Tudor -- Luxembourg and the Ecole Nationale Superieure des Mines de Saint-Etienne -- France. He currently R&D Engineer at CRP Henri Tudor. His research interests are Distributed Systems and mainly Electronic Institution Model for Multi-Agent Systems, Supervision of SLA for Cloud Computing and IoT in the context of smart buildings.