A LAND USE/TRANSPORT MODEL FOR LONG RUN SCENARIOS FOR PASSENGER TRANSPORT IN BELGIUM [1]

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ABSTRACT

The paper describes the general design of the ATLAS model which is currently under development. The ATLAS model is a land use/transport model. Its strength is that it allows taking into account the interaction between transport and land use, such that the mutual influencing of changes in the transport system and changes in land use can be incorporated in the development of long term outlooks. Its aim is to provide policy support in the domain of spatial planning, transport policy and environmental policy, by simulating the impacts of exogenous evolutions and policy measures in long run scenarios.

Keywords: Transport, land use, environment, modelling, long run scenarios

INTRODUCTION

Our transport system poses considerable challenges in terms of congestion, environmental impacts, traffic safety and energy security (European Commission, 2011). Hence, the growing interest in the long run development of transport, in order to get an insight in the further development of these challenges and in the potential contribution of policies to mitigate or solve them. Given the long-term horizon, it is crucial not to consider the transport system in isolation. In this paper we focus on the interactions between land use and transport. These interactions are bi-directional (see, e.g. Hunt et al., 2005; Wegener & Fürst, 1999). On the one hand, the location choice of people and economic activities is one of the many determinants of transport demand. The fact that activities are geographically distributed gives rise to transport needs. On the other hand, the characteristics and performance of the transport

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system affect the development of land use. Transport accessibility fundamentally influences the location decisions by firms and households, real estate development, land prices, and density. In addition, the transport infrastructure and transport flows may also have other spatial effects (e.g., environmental) that may determine the attractiveness of a particular location.

In order to study these aspects, VITO is currently developing the ATLAS (Assessing Transport and Land use Scenarios) model. The model is aimed to function at the system level and to provide input for setting up coordinated policy measures in three policy domains (transport, land use and environment), using long run scenario exercises. The current version is applied to two Belgian regions, Flanders and Brussels.

This paper first describes the general design of the ATLAS model, which consists of two parts: a spatial dynamic land use model and a transport model. The model is designed so that both parts can be used as stand-alone models or as an integrated model. In the integrated version, the transport model is embedded in, and thus called by the land use model. In that case, a number of modules in the stand-alone version of the land use model are (de)activated. The aim of the model is to assess the impact of global demographic and economic trends on the transport flows (and the associated emissions and energy consumption) and land use. In addition, it can be used to evaluate the effects of spatial policy and various forms of transport or environmental policies (pricing, regulation and infrastructure). In our concluding section we highlight some of the further model developments that are planned for the future.

THE ATLAS MODEL

The ATLAS model consists of two integrated parts: a spatial dynamic land use model and a transport model (Figure 1). Both parts are presented briefly in the next paragraphs.

Spatial dynamic land use model

The spatial dynamic land use model is based on the “Land use model Flanders/RuimteModel Vlaanderen” (Engelen et al., 2011). It is a high resolution spatial simulation model and has been used in the past to assess the impact of different policies on future land use. It combines the effects of exogenous socio-economic developments, and of existing and planned policies (spatial planning and transport policy) in the context of scenarios for possible developments in Flanders, Belgium, Europe or the rest of the world. In addition, it evaluates the policy choices in terms of social, economic and environmental criteria by spatially explicit sustainability indicators. The model comprises three interdependent levels: the global, regional and local level.

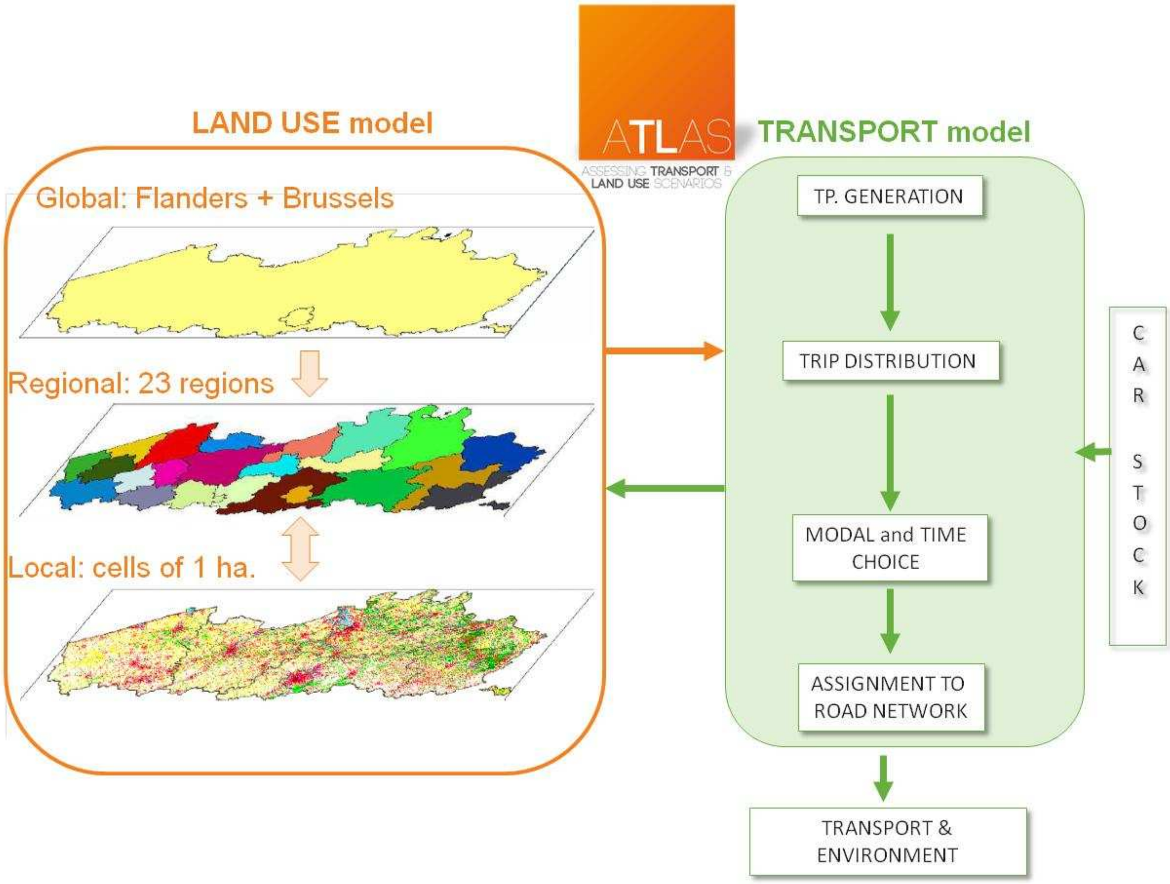

Figure 1 – The structure of the ATLAS model

The global level

The global module takes into account different scenarios for the growth (positive or negative) of the population and the number of persons employed in aggregate economic sectors. The model considers 12 sectors: (1) agriculture, hunting, fisheries and aquaculture, (2) light industry, (3) heavy industry, (4) waste, waste water, drinking water and water distribution, (5) mining, (6) energy, (7) wholesale businesses and transport, (8) retail trade and catering industry, (9) offices and administration, (10) health care, government and other public services, (11) sea harbours, (12) other industrial, commercial or residential activities.

The regional level

The regional module allocates the projected population and employment to the various NUTS3 zones. The growth in the residential and economic sectors is the basis for the demand for land by type of land use in each NUTS3 zone. At this level the following steps are taken:

a. A standard interaction based model assigns the population and activities to the NUTS 3 zones. Each zone competes with others on the basis of the relative transport location, the employment, the size of the population and the type and size of the existing activities. An important element in this calculation is the accessibility to the transport network of each

NUTS3 zone. In addition, the regional attractiveness for an activity is determined by three aggregate indicators that are determined at the local level: the supply of land in terms of its physical suitability, its policy status and its global accessibility (see below).

b. A density model translates the population and the activity per sector into a demand for land. This is communicated to the local level for a detailed assignment. The determination of the density and the assignment of land are governed by the principle of supply and demand. For natural, agricultural and recreational land use the demand for land is set as a hard constraint, to reflect the fact that in these cases policy rather than spatial competition is the determining factor for the assignment of land to the NUTS3 zones.

Alternatively, the regional module can also take into account exogenous assumptions regarding the demographic or economic evolution in the NUTS3 zones.

The local level

The local module assigns the growth in each NUTS3 zone to individual cells of 1 ha. 35 land use types are represented in total. Apart from the population (1 category) and economic activities (12 categories), these consist of 11 natural, 5 agricultural and 6 other types of land use that are considered to be static such as waters, parks and infrastructure.

The size of the population and the employment affect the local module through the amount of land they require. In each NUTS3 zone a cellular automaton determines the resulting land use for each individual cell on the basis of the spatial interactions with the land use in the immediate neighbourhood, given constraints in terms of institutional, physical and transport characteristics. The allocation takes into account the neighbourhood effect (the distance dependent attraction/repulsion between the land use in a cell and the land uses in neighbouring cells in a circular area with a radius of 800 meters). In addition, other determining factors include the suitability of the cell for each activity, policies and the sector specific accessibility. The sector specific accessibility depends on the available transport infrastructure and takes into account the importance that each sector attaches to specific types of infrastructure and the distance of its location to that infrastructure. The development of a market price is not modelled explicitly, but is approximated implicitly by the interaction between the factors that are mentioned above. Finally, account is taken of accessibility indicators that are determined in the transport model.

A feedback exists between, on the one hand, the change in the land use patterns and the quality of the remaining search space at the local level and, on the other hand, the evolutions at the regional level, because this will determine the attractiveness of the NUTS3 zones and therefore the location of people and activities.

Transport model

The transport model is an aggregated model for passenger transport in Flanders and Brussels. The model operates at the level of 6744 traffic zones, which are an aggregate of the cells in the land use model. In each year it starts from the location of the population and jobs and the characteristics of the traffic zones, as defined in the land use model. It takes the evolution of the vehicle fleet along as an exogenous factor. Based on these inputs it determines: (i) the number of trips for three trip purposes: commuting, school and "other purposes", (ii) the origin and destination of the trips; (iii) the modal choice and timing (iv) the route between each origin and destination; (v) the emissions and energy consumption associated with the transport flows. The model also determines accessibility indicators, which will co-determine the land use.

The transport model is written in R [2], C++ and bash. The ATLAS model makes use of several standard R-packages[3], as well as of the TravelR package, which is still in the "prototype" stage and which was tested extensively with real data in the ATLAS model[4].

Transport generation and trip distribution

The transport generation module determines the number of trips leaving from or arriving in the traffic zones. The model starts from the population and employment per traffic zone, aggregating the cells of the land use model. The population is divided further in age categories (0-17, 18-64, 65+) and socio-economic status ((self)employed, student, inactive). Starting from information for the base year and a demographic and economic outlook for future years, the module performs two IPF-procedures ("iterative proportional fitting"). The first is applied to each NUTS3 zone and determines for each traffic zone in the NUTS3 zones the population per age class and the number of students (using a fixed share of students in each age class). The second IPF procedure determines the socio-economic status for the age class 18-64. The results for the employment per traffic zone and the population per traffic zone, age class and socio-economic status are then multiplied by a trip rate per trip purpose. The trip rate can be influenced by the evolution of the generalised transport costs and the GDP per capita.

The trip distribution module follows the standard methodology to determine the origin and destination of the different trips (Ortuzar & Willumsen, 2011).

Modal and time choice

The modal and time choice module determines the modal and time choice for a given number of trips. For the resulting transport flows it also calculates the net tax revenues and the total transport costs. The choice model is defined per zone pair and purpose. The choice of the transport modes and travel periods is such that the generalised cost to make the given number

[2] http://www.r-project.org/
[3] Available via http://cran.r-project.org/.
[4] https://r-forge.r-project.org/projects/travelr/

of trips is minimised. The "production technology" for these trips is given by a nested MCES function (modified constant elasticity of substitution) whose structure is presented in Figure 2. The model incorporates six transport modes: car driver, car passenger, bus/tram/metro, rail, walking and cycling.

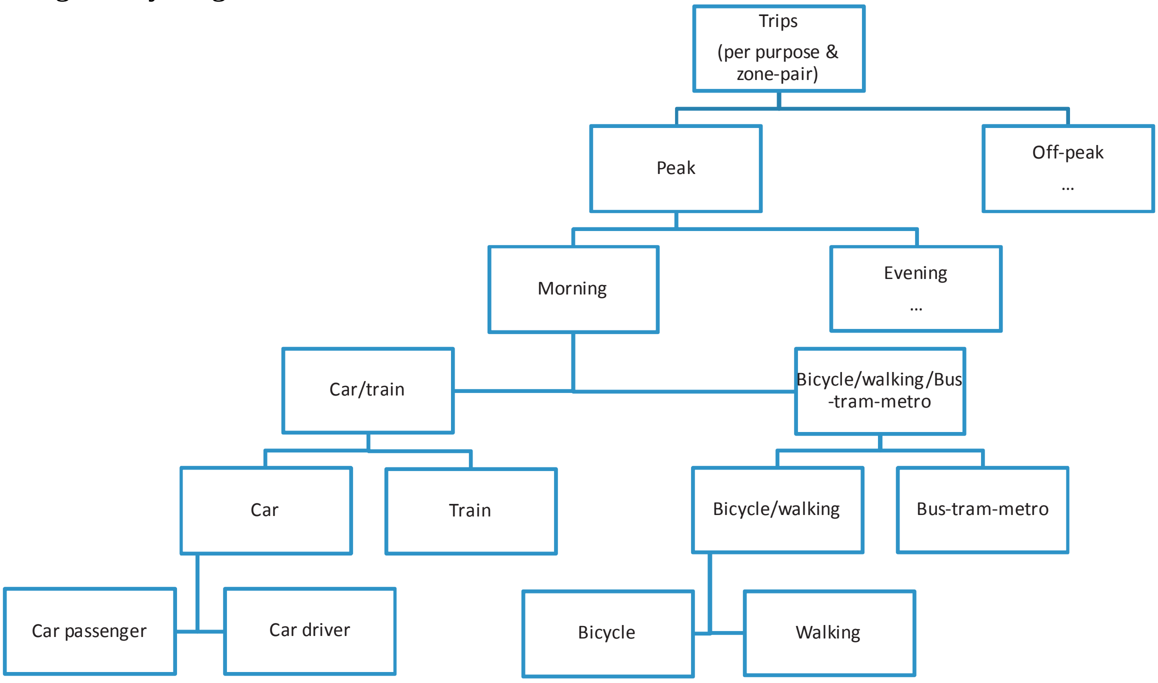

Figure 2 – The structure of the nested MCES function for modal and time choice

For each level k (k=0,…,K) in the nested MCES function the components at the next level (k+1) are chosen such that the production costs are minimised given the MCES production technology:

$$Min \quad C_{k,i} = \sum_{j \in i} p_{k+1,j} x_{k+1,j}$$

$$s.t. \quad x_{k,i} = \Phi_{k,i} \left[\sum_{j \in i} \left(\alpha_{k+1,j}\right)^{\frac{1}{\sigma_{k,i}}} \left(x_{k+1,j}\right)^{\frac{(\sigma_{k,i}-1)}{\sigma_{k,i}}} \right]^{\frac{\sigma_{k,i}}{(\sigma_{k,i}-1)}}$$

$x_{k,i}$ is component i at level k. $C_{k,i}$ is the cost of component i at level k and consists of the input costs of the components j at the next level (k+1) that are related to component i at level k. $j \in i$ indicates that the set of components $x_{k+1,j}$ is related to $x_{k,i}$. $p_{k+1,j}$ is the unit price of component $x_{k+1,j}$. The cost $C_{k,i}$ is minimised subject to the constraint that $x_{k,i}$ is produced according to an MCES function. In this function $\Phi_{k,i}$ is a constant that defines the measuring unit. $\alpha_{k+1,i}$ is a weighting factor. $\sigma_{k,i}$ is the substitution elasticity and gives the sensitivity of the ratio of two underlying components at level k+1 w.r.t. the ratio of the input costs of those components.
Solving the minimisation problem leads to the following demand functions:

$$x_{k+1,j} = \frac{x_{k,i}}{\Phi_{k,i}} \alpha_{k+1,j} \left(\frac{p_{k,i}}{p_{k+1,j}} \right)^{\sigma_{k,i}}$$

$p_{k,i}$ is a price index and is defined as follows:

$$p_{k,i} = \left[\sum_{j \in i} \alpha_{k+1,j} \left(p_{k+1,j} \right)^{(1-\sigma_{k,i})} \right]^{\frac{1}{(1-\sigma_{k,i})}}$$

The cost of component *i* at level *k* is then given by:

$$C_{k,i} = x_{k,i} \Phi_{k,i} p_{k,i}$$

Transport demand depends on the generalised cost which equals the sum of the monetary and time costs. For road transport and the public transport modes the generalised cost is determined by means of the assignment module of the previous model year (see below). For car passengers, cyclists and pedestrians only time costs are taken into account.

The MCES functions are calibrated (for each zone pair, mode and purpose), using the observed OD matrix and calculated costs (see further) for the base year such that the transport demand elasticities with respect to the generalised costs are in line with values from the literature. The parameters of the functions are assumed to remain stable over time. For zone pairs with zero trips in the base year and non-zero trips in the simulation years, a default MCES function is used that is calibrated on the basis of the total number of trips in the base year.

Assignment

The assignment module assigns the trips between the zone pairs to the transport network. For each zone pair and transport mode it determines the distance, the travel time and the toll that has to be paid (when relevant). The methodology that is used depends on the transport mode.

For the **non-motorised modes** (walking and cycling) it is assumed that there is no interaction with the other modes on the network, which means that abstraction is made of their potential contribution to congestion. In this case the route choice is determined using the shortest path algorithm.

For **cars and bus/tram** the model does take into account congestion and calculates a Wardrop equilibrium. In such an equilibrium no vehicle can lower its total costs by changing routes. Road traffic is divided into two assignment classes (cars and bus/tram). The cost function takes into account the monetary costs that are proportional to distance travelled, the toll that has to be paid and the time costs. The value of time is a weighted average of the value of time for the different trip purposes.

For the car passenger mode we assume that the financial costs are borne entirely by the car drivers. For some cases (for example, parents driving their children to school) this is more realistic than in others (e.g., organised car pool system). We also assume that the travel time between the zone pairs equals that of car drivers. The car drivers are therefore assumed not to lose time when picking up their passengers. Again, this assumption will be more realistic in some cases than in others.

An Akçelik function is used to model the relation between transport flows and travel times on each link.

For bus/tram the routes set by the public transport companies determine the congestion on the network, while the cost for the public transport users depends on the routes and connections they take.

Due to time constraints the ATLAS model however uses a more simplified approach. Each public transport user is taken to minimise his/her generalised transport costs which consist of time costs and (fixed) ticket cost. We assume that the routes taken by the public transport companies correspond with the routes that minimise the user costs. It is assumed that the time needed for a bus or tram to traverse a link on the transportation network is proportional to the time taken by a private car, up to a stochastic proportionality factor which reflects to time needed for alighting and boarding. This corresponds with a public transport system that adjusts itself perfectly to the choices of the travellers.

Taking into account the small share of public transport vehicles in total traffic, we think that the misrepresentation of the effect on network congestion is relatively limited (except maybe in some dense urban area or close to interchanges). However, this approach overlooks the financial implications for the public transport companies of this extreme adjustment to demand and does not take into account that public transport routes are often determined by political constraints.

Improving this approach would entail modelling route choice by passengers that take into account the existing public transport network. This is, is one of the priority future development paths of the ATLAS model.

For **rail transport** we assume that the distance in equilibrium equals that of passenger cars multiplied by a stochastic proportionality factor, such that the average distance equals that of a car. The model imposes an exogenous train speed and assumes that each trip requires a fixed travel time to and from the station. The passenger flows on the train network do not affect congestion on the road network.

An alternative would be to assign each traffic zone to a railway station and to calculate the shortest route between the stations via the rail network. This will be explored later.

In the current version of the ATLAS model there is no feedback between the assignment module and the modal and time choice module. So, if in equilibrium the generalised costs between a zone pair for a particular mode are higher than in the previous model year, this will not affect the modal and time choice in the current year. It will however have an impact in the next model year. This approach is due to the long computing time required for the assignment module. It is not a priori clear how unrealistic this assumption is. The alternative approach with a perfect convergence between modal and time choice on the one hand and assignment on the other hand probably also lacks realism by assuming a high degree of rationality. We think it is not unreasonable to assume that the modal choice is more stable in the short run than the exact route that is taken. However, in future versions of the model we hope to explore this further.

Environmental module

The environmental module computes the total energy use and the emissions of air pollutants and greenhouse gases. A distinction is made between exhaust, non-exhaust and indirect emissions. The last category is caused by the production and transport of energy, while non-exhaust emissions are related to the abrasion of tyres, brakes, etc. The model includes the following pollutants: carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), non-methane volatile organic compounds (NMVOCs) and sulphur dioxide (SO_2). In addition, three greenhouse gases are modelled: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The model calculates not only the total emissions but also the emissions per link of the transport network. In a later stage this would allow to couple the model with air quality models. The model could also be expanded to include the emissions of water pollutants by transport.

Data of the transport model

For the base year (2008) the transport model is tuned to data that were provided by the Flemish Traffic Centre. The data cover 6744 traffic zones in Flanders and Brussels. They include the definition of the traffic zones and the network, socio-demographic data, origin-destination matrices for passenger transport by trip purpose (commuting, school, shopping, recreation/social visits, other) for four 4 contiguous periods of the day and origin-destination matrices for passenger transport by trip purpose and mode for 2 hours of the day (morning and evening peak).

The data were supplemented by information from various sources on the monetary costs of transport. In addition, the HEATCO project (2006) served as a source for the value of travel time and the E-Motion model provided us with emission factors and fuel consumption factors (de Vlieger et al., 2011, 2012a,b,c).

At this stage of the model development some data are still missing. As a consequence, some aspects could not yet be incorporated in the present version of the model. More particularly, land use in zones outside of Flanders and Brussels, transport to and from these zones and freight transport flows on the road network are not yet included. This implies that simulations carried out with the current version of the model should still be seen as a test of the model prototype, rather than as fully-fledged scenario exercises. A next step in the model development will consist of incorporating the missing elements.

The interaction between the spatial dynamic land use model and the transport model

In their survey of land use/transport models, Hunt et al. (2005) make a distinction between frameworks that are fully integrated and those that are connected. In the first case, the origin-destination linkages are determined within the land use part of the modelling system. In the connected approach, the transport side determines the origin destination choice. Such models implicitly assume that the choice of the home location is a long term decision in which the accessibility of jobs is only one of numerous determining elements. The ATLAS model follows the second approach.

In the ATLAS model there is a two-way interaction between the land use and transport model. First of all, the land use model determines in each year the population and employment per traffic zone. Starting from these results, the transport model calculates the transport flows, the generalised costs and accessibility indicators that will be used as an input in the land use model in the next year.

Geurs (2006) proposes to define accessibility as the extent to which land use and the transport system offer the possibility to individuals to reach activities or destinations by using transport modes. He puts forward a classification of accessibility indicators:

- Infrastructure based indicators: e.g., the average travel time or the congestion level; such indicators do not take into account the actual traffic flows at a given moment.
- Location based indicators: e.g., the number of jobs that can be reached within 30 minutes, or the weighted average of the accessible jobs, with the weight depending on the distance; a problem is that these indicators do not take into account transport volumes and costs.
- Person based indicators: this refers to the activities in which a person can participate at a given moment; it comes close to the conceptual definition given above, but can be implemented only with state-of-the-art activity-based transport models.
- Utility based indicators: these indicators measure the benefits that people derive from their access to spatially distributed activities. These measures are most common in integrated land use-transport models.

Apart from location based indicators, the ATLAS model also bases itself on de Palma et al. (2005) for its definition of accessibility indicators. For each transport zone the model calculates accessibility from two points of view: as a point of origin and as a point of destination. The accessibility of an origin(/destination) zone is calculated as the weighted average of the number of individuals that leave from(/arrive in) that zone, where the weight is calculated as the benefit that each traveller derives from his/her trip. The benefits from a trip are calculated using the transport model. In the ATLAS model the benefits are set equal to the generalised costs: a trip will be made only if the benefits are at least as high as the costs. In this case the indicator is therefore a lower limit of the real benefits.

Type of scenario exercises

The ATLAS model is set up to perform different types of scenario exercises. First of all, it can calculate the impact of general evolutions on transport flows (and the related emissions and energy use) and land use. These general scenarios include the general demographic and economic evolutions, the evolution of the monetary transport costs before taxes/subsidies, the composition of the car stock and the emission and energy consumption factors of the vehicles. All of these evolutions are considered to be exogenous to the model, in the sense that they are assumed not to be influenced by land use or transport policies.

Secondly, the ATLAS model can simulate the effect of land use, transport or environmental policies.

The land use policies can be introduced both at the regional and local level of the land use model. At the regional level an upper or lower limit can be imposed for the different activities. One can also impose certain densities for the transformation of population/activities into land use demand, instead of delegating the determination of these densities to the land use model. At the local level of the land use model spatial planning determines the policy status of the individual cells of 1 ha.

The transport policies include changes in pricing, regulation and infrastructure. Regulation may consist of emission regulation or fuel consumption standards. These will affect the characteristics of the vehicle stock (composition, emission factors, fuel consumption) and the monetary transport costs. Pricing measures consist of the reform of transport taxes/subsidies (which are negative taxes). These include the fixed taxes on car purchase and ownership, variable car taxes, public transport taxes and taxes on non-motorised modes. It should be noted that the impact of changes in vehicle taxation on the composition of the vehicle stock is not modelled in the ATLAS model and needs to be derived from other models. Finally, transport infrastructure measures concern the expansion or downsizing of existing infrastructure or the provision of new infrastructure.

The environmental policies that can be simulated with the ATLAS model are related to land use and transport. In the case of land use it concerns the determination of the policy status of the land cells in order to reach certain environmental objectives. For transport these consist of e.g. regulation of emissions and energy use, the promotion of certain vehicle types or infrastructure measures aiming to defragment natural areas.

CONCLUDING REMARKS

At this moment the ATLAS model is still under development. Therefore no simulations can yet be presented. The strength of the modelling tool is that it allows taking into account the interaction between transport and land use, such that the mutual influencing of changes in the transport system and changes in land use can be incorporated in the development of long term outlooks. The model is set up for the assessment of the impact of global demographic and economic trends on the transport flows (and the associated emissions and energy consumption) and land use. In addition, it can be used to evaluate the effects of spatial policy and various forms of transport policies (pricing, regulation and infrastructure). Future developments include, apart from adding missing data, a more realistic modelling of public transport and the introduction of an iterative process between modal & time choice on the one hand and assignment on the other hand.

REFERENCES

de Palma, A., K. Motamedi, J. Moyano, D. Nguyen-Luong & N. Picard (2005). Development of a dynamic integrated Land use-Transportation Model (45th ERSA Congress).

De Vlieger, I., I. Mayeres, H. Michiels, M. Vanhulsel, D. Gusbin, B. Hoornaert, M. Vandresse, A. De Witte, C. Macharis & L. Turcksin (2012a). PROLIBIC Final Report. Project funded by Belgian Science Office (Research Programme Science for a Sustainable Development).

De Vlieger I., B. Degraeuwe, M. Vanhulsel, C. Beckx & J. Vankerkom (2012b). Actualiseren MIMOSA-model (MIMOSA4.2), VITO.

De Vlieger I., B. Degraeuwe, M. Vanhulsel, C. Beckx, J. Vankerkom & W. Lefebvre (2012c). MIMOSA 4.2 – Prognoseberekeningen voor wegverkeer in Vlaanderen, VITO.

De Vlieger, I., L. Schrooten, M. Vanhulsel, B. Degraeuwe & Jean Vankerkom (2011). E-Motion, Annex 1 to LIMOBEL final report. Project funded by Belgian Science Office (Research Programme Science for a Sustainable Development).

De Vlieger, I., L. Pelkmans, L. Schrooten, J. Vankerkom, M. Vanderschaeghe, R. Grispen, D. Borremans, K. Vanherle, E. Delhaye, T. Breemersch, C. De Geest (2009), Transport: referentie- en Europa-scenario, Wetenschappelijk rapport, Toekomstverkenning MIRA 2009, Milieurapport Vlaanderen, Vlaamse Milieumaatschappij, Mechelen.

Engelen, G., Van Esch L., Uljee, I., De Kok, J-L., Poelmans L., Gobin, A., & van der Kwast, J. (2011). Ruimtemodel: Ruimtelijk-Dynamisch landgebruikmodel voor Vlaanderen, VITO-rapport 2011/RMA/R/242 december 2011, 256 p.

European Commission (2011). White paper, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. COM (2011) 144 final.

European Commission (2011). Energy Roadmap 2050. COM(2011) 885 final.

Geurs, K. (2006). Accessibility, land use and transport, Accessibility evaluation of land-use and transport developments and policy strategies. Ph.D. dissertation University of Utrecht.

HEATCO project (2006). Deliverable 5: Proposal for Harmonised Guidelines. Project funded by the 6th Framework Programme.

Hunt, J., D. Kriger and E. Miller (2005). Current operational urban land-use transport modelling frameworks: A review. Transport Reviews 25(3): 329–376.

Ortuzar, J. and L.G. Willumsen (2011), Modelling Transport, Wiley.

Wegener, M. and F. Fürst (1999). Land-Use Transport Interaction: State of the Art. Deliverable 2 of TRANSLAND (FP4 European Commission). Berichte aus dem Institut für Raumplanung 46, Institut für Raumplanung, Universität Dortmund.