GIS-BASED MULTI-AGENT TRAFFIC MICRO SIMULATION FOR MODELLING THE LOCAL AIR POLLUTION

M. khalesian, P. Pahlavani, M. R. Delavar*

Center of Excellence in Geomatics Eng. and Disaster Management, Dept. of Surveying and Geomatics Eng., College of Eng., University of Tehran - (khalesian, pahlavani, mdelavar)@ut.ac.ir

Commission VIII, WG VIII/3

KEY WORDS: GIS, Decision Support, Pollution, Modelling, Spatial, Dynamic, Spatial Information Sciences

ABSTRACT:

Air pollution from motor vehicles is one of the most serious and rapidly growing problems in metropolitan areas. It is occurred especially in major arterial streets inside the metropolitan central district because of the heavy traffic congestion suffering. Although transportation networks operate as an integrated system, at a regional level we can safely assume that local urban congestion will not affect other urban areas that are geographically distinct. This suggests a manageable problem, i.e., instead of solving for region-wide congestion patterns, we can augment the current capabilities of logistical air quality management system (AQMS) software with a module to predict localized urban congestion on a special major arterial street and its impacts on the amount of generated air pollution. In this paper, a GIS-based multi-agent traffic micro-simulation decision support approach utilized in order to manage and control navigation under dynamic traffic identification and modelling to determine the air pollution, particularly CO, generated by heavy traffic congestion in one of the major arterial urban streets. Our preliminary work in this area indicates that agent technology can significantly help designers and decision makers in this context.

1. INTRODUCTION

Decisions are often evaluated based on quality of the processes behind. Decision making itself, however, is broadly defined to include any choice or selection of alternative course of action, and is therefore of importance in many fields in both the social and natural sciences, including geospatial information sciences. It is in this context that a customized geospatial information system (GIS) i.e., a spatial decision support system (SDSS) increasingly is being used to generate alternatives to aid decision- makers in their deliberations.

Air quality management systems (AQMS) can be defined as a regulator of the amount, location and time of pollutant emissions to achieve some clearly defined set of ambient air quality standards or goals. For an efficient AQMS, there is a need to define a SDSS.

Air pollution from motor vehicles is one of the most serious and rapidly growing problems in metropolitan areas. It is occurred especially in major arterial streets inside the metropolitan central district because of the heavy traffic congestion suffering. Traffic congestion has substantial negative effects on urban residents and firms. These impacts include air pollution, loss of productivity and restricted accessibility to the urban environment. Traffic congestion patterns are spatially complex and are dynamic phenomena i.e., they do not occur everywhere, all at once. Congestion occurs in specific locations and propagates through the network over time as congested conditions on a link spread to nearby links. In addition, since many urban transportation networks are operating at near-capacity, they are especially vulnerable to congestion occurring as the result of incidents such as accidents and infrastructure failures (e.g., bridge closings, construction). These incidents result in congestion patterns that propagate from the localized incident through the network, potentially resulting in serious flow disruption and so, the severe air pollution.

Although transportation networks operate as an integrated system, we can safely assume that local urban congestion will not affect other urban areas that are geographically distinct (Gualtieri and Tartaglia, 1998). This suggests a manageable problem, i.e., instead of solving for region-wide congestion patterns, we can augment the current capabilities of logistical AQMS software with a module to predict localized urban congestion on a special major arterial street and its impacts on the amount of generated air pollution. So, we intended to determine the air pollution, particularly CO**,** generated by heavy traffic congestion in one of the major arterial urban streets. The main problem for this determination is the location of traffic congestion identification as well as its measurement.

In this paper, a GIS-based multi-agent traffic micro-simulation decision support approach utilized in order to manage and control navigation due to dynamic traffic identification and modelling to determine the air pollution, particularly CO, generated by heavy traffic congestion in one of the major arterial urban streets.

In section 2, the reasons for integration of multi-agent micro simulation into the problem in hand are exhibited. In section 3, the proposed method is represented. Experiments are exhibited in section 4 and finally the results are introduced in section 5.

* Corresponding author.

2. INTEGRATED MULTI-AGENT MICRO SIMULATION SYSTEM

Most of the proposed models for AQMS are based on the allocated balanced traffic volume assignment achieved from Origin-Destination (OD) matrix. So, these models are unreal because the measurement of air pollution would not be according to the real traffic volume and it is not possible to measure the air pollution for each street segment. The GIS-based multi-agent traffic micro simulation not only proposed a solution for the above problems but also can measure street air pollution due to future development of transportation plans in different level of services.

Real systems such as problem in hand require abilities for accurately measure the influence of different multi-agent coordination strategies in an unpredictable environment (Horling *et al*., 2000). A significant advantage of multi-agent systems (MAS) over traditional designs is the fact that the system is distributed. The decentralized, partially autonomous and redundant nature of such a system makes them less sensitive to certain classes of faults. This decentralization, however, also makes it difficult to analyze these systems.

MAS are composed of autonomous, interacting, more or less intelligent entities (Braubach *et al*., 2004). The agent metaphor has proven to be a promising choice for building complex and adaptive software applications, because it addresses key issues for making complexity manageable at a conceptual level. Furthermore, agent technology can be seen as a natural successor of the object-oriented paradigm and enriches the world of passive objects with the notion of autonomous actors.
The use of autonomous and intelligent agents allied to the drivers' actions is now central in traffic and transportation navigation systems. This has brought about the navigation need for assessing other performance measures, which demands more powerful and expressive modelling to yield the simulation tools for measuring pollutants due to motor vehicles in street. Thus, much work should be carried out to develop new-generation of GIS-based multi-agent traffic micro-simulation models.

The proposed microscopic multi-agent traffic network simulation has been utilized in order to determine dynamic traffic flow identification and modelling as inputs to the proposed air pollution model.

3. METHODOLOGY

The proposed method uses a discrete time dynamic network assignment procedure that simulates network flow at detailed temporal resolutions. All individuals (agents) have their own plans about their destinations. The GIS-based multi-agent traffic micro-simulation executes all those plans which simultaneously pass through the street under investigation. So, we can obtain the results of interactions among the plans, for example congestion.

In the multi-agent traffic micro-simulation air pollution determination approach, the car following model has been used. Car following model describes how a car speeds up and brakes. The car following model computes at each step of the simulation a new acceleration depending only on the vehicle's speed, the speed and distance of the car ahead of it. Also, the lane changing model describes how a driver decides to change the lane. This decision is based on two main criteria for the agent including the safety criterion i.e., is it safe to go on the other lane? And incentive criterion i.e., does the agent get a reward to go on the other lane? (Kesting *et al.*, 2007).The other capabilities of this approach are its implementation on vector data environment by considering each car real length as well as its minimum and maximum acceleration without car accidents.

After dynamic traffic volume identification and modelling of each street segment under investigation, modelling and determining street air pollution were initiated. Among various techniques for simulating dispersion of pollutants due to motor vehicles in streets, the semi-empirical approach appears to be the most convenient one for practical use. The proposed vehicular pollution modelling is focused on pollutants, whose dispersion processes do not involve chemical or photochemical reactions i.e., CO. The data used for determining air pollution in the proposed approach is the number and the speed of vehicles achieved from the above GIS-based multi-agent traffic micro simulation approach, wind direction, wind speed, solar radiation, air temperature and building heights.

Figure 1 shows the general steps of the proposed algorithm for GIS-based multi-agent traffic micro simulation for modelling the street air pollution whose details are presented in sections 3.1 and 3.2, respectively.

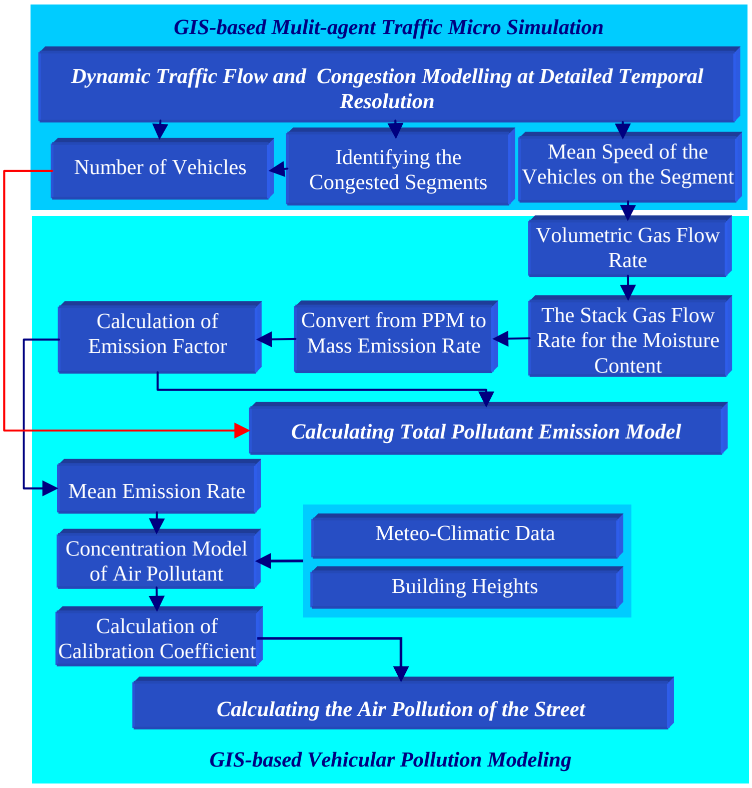

Figure 1. The proposed work flow of the GIS-based multi-agent traffic micro simulation for modelling the street air pollution

3.1 GIS-based multi-agent traffic micro simulation

A multi-agent system (MAS) is composed of agents which perceive information about their environment and execute actions which modify their own state and the environment. Furthermore, by acting on themselves or the environment, agents can cause communicative events to be raised which can affect other entities.

Communicative events in such a system are transmitted directly from the sender to the receiver. However, we sometimes need to control, govern or define laws about the events raised by the communication.

Unlike the agents, the environment in the proposed method can just react to events which are intercepted and then send messages to itself or to the agents. Section 3.1.2.2 describes laws which rule the environment.

3.1.1 Agents and environment: Figure 2 presents a graphical description of the agents and their environment.

In Figure 2, rounded rectangles are agents which can contain internal objects including:

- **Vehicle** has 3 state attributes: its position (relative to its current segment), speed and lane position. Each vehicle has: a Plan which is an ordered collection of RoadSegment indicating which way to take; a Behaviour which describes its acceleration, deceleration and lane changing behaviour.
- **VehicleCreator** is a dedicated agent which takes care of creating new agents in the system. Its state is only described by the number of vehicles which have been created and are not yet destructed (i.e. the number of vehicles currently alive and created by this agent).

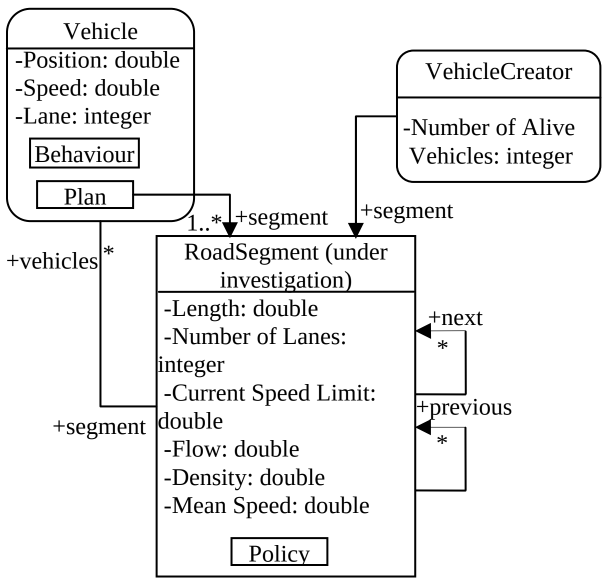

Figure 2. A UML class diagram for the proposed agents and environment

The road is divided in segments. Each vehicle lives in a RoadSegment (as shown in Figure 2) which can be considered as a continuous space. Each one is connected to its next following segments and its previous preceding segments. Vehicles can only move from their current segment to one of the next segments. The segment has a few constant attributes such as length, number of lanes and a few variable attributes such as current speed limit, flow, density and mean speed). The constant attributes are fixed at start-up and variable attributes change during the execution of the simulation. All these attributes are part of the environment and can be perceived by agents.

The obtained constant and variable attributes are stored in the GIS-based spatio-temporal urban traffic network database for the purpose of manipulation and retrieval.

In the proposed method, the choice for a continuous space is given by the better precision and the light implementation that follows, but one could consider a discrete space. Nagel (2004) shows how to build cellular automata simulation with discrete space. It should be easily transposed to our multi agent-based simulation.

3.1.2 Dynamic description: The time of the simulation in the proposed method is discrete. We send a time step message to every agent at each step of the simulation, and they return an action depending on what they perceive and what their behaviour is described by its internal model (see section 3.1.3).

As mentioned in section 3.1, the environment has a governor role and can react to some events. It can also generate events if it is necessary.

In this section we describe actions made by agents and events raised by agents or by the environment itself. For every event the associated law of the environment is textually described.

3.1.2.1 Events: Figure 3 shows the events we identified and classified according to the categories in the work of Schumacher and Ossowski (2006). A category does not change the behaviour or the processing of an event; this is only to see what kind of event they are. The description and associated laws of each of the events are described in following sections.

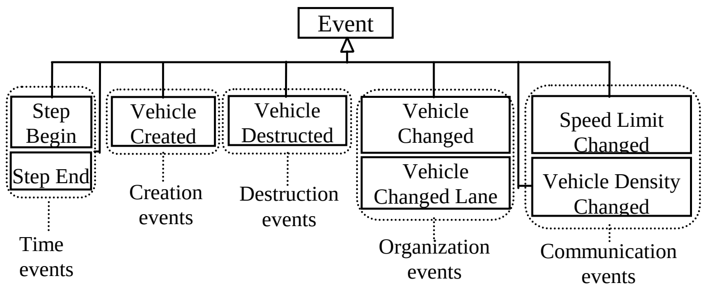

Figure 3: Events hierarchy diagram

3.1.2.2 Environment: In the following the laws which rule our governing environment are described:

- *SpeedPolicyChangedEvent*: is generated each time the speed restriction changed in a segment. The governing environment will tell the neighbor segments to reconsider their current speed limit.
- *StepBeginEvent*: is an internal event which is generated by the environment itself to warn the segment that a time step has begun.
- *StepEndEvent*: is the same type of event as *StepBeginEvent* but it warns the segment against the end of a time step event.
- *VehicleDestructedEvent*: is raised by the environment each time a vehicle finished its planning and should die.

- *VehicleDensityChangedEvent*: is raised each time the density of the segment has changed. It tells the environment to reconsider its speed limit.

3.1.2.3 Agents: This section describes the actions made by the proposed agents and the events they can raise. The way agents behave is described in section 3.1.3.

- **VehicleCreator:** VehicleCreator perceives how many vehicles are already alive in the environment in order to act. Depending to the environment's decision, it creates a new vehicle. This is the only action it can undertake.
  VehicleCreatedEvent is launched by VehicleCreator each time it creates a new vehicle (Figure 4).

```
RAISER: creator
PARAMETERS: vehicle, segment, creator
1: tell segment that vehicle will enter in its space
2: warn vehicle that it entered in segment
3: warn creator that a new vehicle is alive
```

Figure 4. The algorithm of vehicle created event

- **Vehicle:** Vehicle perceives neighbor vehicles' and segments' current parameters and takes action based on this. It can only update its speed and move forward.
  VehicleChangedSegmentEvent is posted by Vehicle every time it leaves a segment and enters a new one (Figure 5).

```
RAISER: vehicle
PARAMETERS:currentSegment,targetSegment, vehicle
1: warn the currentSegment that vehicle leaves its space
2: if newSegment exists then
3: ask the targetSegment to add vehicle to its space
4: warn the vehicle that it entered in segment
5: else
6: raise a VehicleDestructedEvent with parameter vehicle
7: end if
```

Figure 5. The algorithm of vehicle changed segment event

  VehicleChangedLaneEvent is posted by Vehicle every time it changes its lane position.

3.1.3 Car following model: The proposed model is inspired by the discrete time and continuous space car following model described in the work of Treiber *et al.* (2006) and is known as the Intelligent-Driver Model (IDM). Figure 6 is a formal description of the algorithm used to compute the new acceleration at each step. This model makes the vehicle accelerate to its speed objective. Unlike the other model, this one does not have a constant acceleration. It decreases from the initial acceleration (a) to zero when approaching the speed objective (s_o). The deceleration value increases from b and is not limited in the theoretical model. Because of this, the vehicles can have unrealistic deceleration, but the system is collision free. We tried to limit the maximal deceleration to $3b$ and we got more a realistic behavior even if the value is higher than a realistic car deceleration.

Require: $v, v_f, s, T, v_{limit}, a, b, s_{min}$

1: $v_o \leftarrow humanaizeSpeed(v_{limit})$

2: $\Delta v \leftarrow v_f - v$

3: $s^* \leftarrow max\{s_{min}, s_{min} + vT + \frac{v\Delta v}{2\sqrt{ab}}\}$

4: $a_c \leftarrow a[1 - (\frac{v}{v_o})^4 + (\frac{s^*}{s})^2]$

5: **return** $max\{-3b, min\{a_c, a\}\}$

Figure 6. The algorithm of IDM car following model

s is the distance to the car ahead and v_f is the speed of the vehicle ahead (f means "forward"). v_{limit} is the speed limit on the current segment, a and b are the maximum acceleration and deceleration of the car, s_{min} is the minimum distance to the car ahead (typically about 2 meters). T is the safety time to forward vehicle.

3.2 GIS-based vehicular pollution modelling

As shown in Figure 1, the steps of the the modeling process is as follows:
The first step is to calculate the stack's volumetric gas flow rate ($\dot{V}$) using Formula 1 (Gualtieri and Tartaglia,1998):

$$\dot{V}(m^3/min) = \text{Mean speed of vehicles(m/s)} * \left[\pi * (\text{diameter of dipersion(m)})^2/4\right] * 60(\text{Sec/min}) \quad (1)$$

Mean spead of vehicles is achieved from the proposed multi-agent simulation (section 3.1). Formula 1 is then modified to correct the stack gas flow rate for the moisture content and standard conditions using Formula 2 (Gualtieri and Tartaglia, 1998):

$$\text{Dry } \dot{V}\ (m^3/min) = \dot{V}(m^3/min) * \frac{273.15\ K}{T_{actual}} * \frac{P_{actual}}{1atm} * (1 - \text{humidity}) \quad (2)$$

where P_{actual}: Actual Pressure and T_{actual}: Actual Temperature.
The next step is to convert car volume (ppm) achieved from the proposed multi-agent simulation (section 3.1) to mass emission rate (kg/h) as follows (Gualtieri and Tartaglia,1998):

$$\text{MassEmissionrate(kg/h)} = \text{ppm} * \text{density of air at standard condition} * \text{Dry } \dot{V} * 60(\text{min/h}) * \frac{MW_{substance}}{MW_{air}} \quad (3)$$

where $MW_{substance}$: Mass volume of Substance and MW_{air}: Mass volume of Air
The emission factor is calculated using Formula 4 (Gualtieri and Tartaglia, 1998):

$$E_g = \text{Emission factor} = \frac{\text{Emission rate}\left(g/_{hour}\right)}{\text{Fuel feed rate}\left(kg/_{hour}\right)} \quad (4)$$

Q_s = Mean Emission Rate = Emission factor / Length of the road (5)

The emission factor E_g due to road vehicles belonging to group g is expressed as the mass of pollutant per unit length as a function of the average travel speed, V_m, achieved from the proposed multi-agent simulation (section 3.1) . Total pollutant emission, Q, produced by the traffic flow, *f*, of *N* vehicular groups is computed using Formula 6 (Gualtieri and Tartaglia, 1998) :

$$Q = \sum_{g=1}^{N} \frac{c_g}{100} * E_g(V_m) * f \qquad (6)$$

where c_g is the percentage of vehicular group *g* with respect to the vehicle fleet. Concentration is calculated by adding local and areal concentration. In this paper our objective is modeling the local concentration which is more effective areal concentration. Local Contribution to concentration is calculated by different approaches (i.e. Zannetti (1990); DePaul and Sheih (1986)). The model developed by Gualtieri and Tartaglia (1998) is more useful for calculating the local contribution to concentration because of considering more elements of meteo climatic variables. This model is based on the calibration process. The street canyon model used is based on Formula 7 (Gualtieri and Tartaglia, 1998):

$$C_l = a\left[\frac{Q_S}{U+0.5}\right] * F + bT + cH + \sum_i d_i Rad_i + k_0 \qquad (7)$$

where: C_l(µg/m^3): modeled CO concentration; Q_s (g/ms): mean emission rate; F (m^{-1}): shape factor (F_W ,F_L ,F_I) , depending on the specific sector (Table 1); U (m/s): air wind speed; T (^{o}C): air temperature; H (m): mixing height; $\sum Rad_i$ (W/m^2): solar radiation; a,b,c,d,k_0 : model linear coefficients to be calibrated.
Q_s is calculated according to Formula 5. F is calculated with respect to Table 1.

U, T, H, $\sum Rad_i$ have been obtained from Iran Meteorological Organization.

Sector	Shape factor	Value(m-1)
Windward	F_W	$7 * \frac{h-z}{h*w}$
Leeward	F_L	$7 * \frac{1}{\sqrt{x^2+z^2}+L_0}$
Intermediate	F_I	$(F_W + F_L)/2$

where *h*: buildings mean height; w: street canyon width; *x*: distance of the receptor from street axis; *z*: height of the receptor; L_0: Vehicles mean width, generally assumed (Meters).

Table 1: Shape factors values, F, as a function of sector geometrical features (Tartaglia *et al.* (1995))

4. EXPERIMENTS

The proposed methods were implemented by ArcGIS utilization and customization. ArcGIS has a feature in architectural design, which enables it to be developed by COM programming in any visual environment.
To evaluate the performance of the outlined method, we performed experiments using actual 2D and constructed 3D maps of a part of the center of Tehran urban traffic network at a scale of 1:2000 including roads and buildings (Figure 7). In addition, each result given up was performed on Intel® Core™ 2 Duo CPU T7300 (2 and 1.99GHz) with 2 GB of RAM.

Figure 7. The actual constructed 3D map and the street under investigation

Table 2 shows the initial parameters of the used car following model (see Figure 6).

No.	Initial parameter of safe distance car following model	Value
1	*T*	1.5 (sec.)
2	v_{limit}	75 (Km/h)
3	*a*	0.3 (m/sec.^{2})
4	*b*	3 (m/sec.^{2})
5	s_{min}	2 m

Table 2: Initial parameters of the car following model used

The proposed GIS-based multi-agent traffic micro-simulation (section 3.1) executes all those agents' plans which simultaneously pass through the street under investigation referring to the morning peak hour i.e., 7:30 to 8:30 A.M. (Figure 8). So, we can obtain the results of interactions between the plans for example congestion.

Figure 8. The GIS-based multi-agent traffic micro simulation for the street under investigation

In particular, in order to simulate pollution levels, the reference time period, 7:30 to 8:30 A.M., has made it necessary to set up an adequate meteorological scenario. The meteoclimatic scenario was set up according to the 'worst' scenario, enabling the highest air pollution condition to be reached in the street under investigation. The worst scenario has been defined on the basis of a historical data series collected by the Fatemi observatory meteo station in Tehran, Iran, which covers the entire winter of 2007. The worst scenario describing the worst meteorological conditions with respect to air quality, required a previous study of the role played by all main atmospheric parameters in affecting pollutant dispersion caused by vehicular traffic in the street under investigation. In particular, the mode i.e., the most frequent value, was chosen for wind direction and solar radiation, whereas to obtain reliable concentration estimations performed by the dispersion model, a lower threshold equal to 1.5m/s was chosen for wind speed (Hanna et al., 1982). For the street under investigation, CO concentrations are calculated at 3m over the ground level and 1m from building walls and assumed not changing along the segment axis of the street and mapped concentrations are averaged between both canyon sides. The experimental measurements are given in Figure 9.

Figure 9. An example of CO ($\mu g/m^3$) concentration mapping within the study area in a worst winter scenario.

5. CONCLUSION

In this paper, a GIS-based multi-agent traffic micro-simulation decision support approach utilized in order to measure air pollution, particularly CO, generated by heavy traffic congestion in one of the major arterial urban streets in Tehran.

The proposed method uses a discrete time dynamic network assignment procedure that simulates network flow at detailed temporal resolutions. All individuals (agents) have their own plans about their destinations. The proposed GIS-based multi-agent traffic micro-simulation executes all those plans which simultaneously pass through the street under investigation. So, we can obtain the results of interactions between the plans e.g., congestion. In the proposed multi-agent traffic micro-simulation air pollution determination approach, we used the car following model. Car following model describes how a car speeds up and brakes. The proposed car following model computes at each step of the simulation a new acceleration depending only on the vehicle’s speed, the speed and distance of the car ahead of it. Also, our lane changing model describes how a driver decides to change the lane. This decision is based on two main criteria for the agent including the safety criterion i.e., is it safe to go on the other lane? And incentive criterion i.e., does the agent get a reward to go on the other lane? The other capabilities of this approach are its implementation in vector data environment considering each car real length as well as its minimum and maximum acceleration without car accidents.

After dynamic traffic volume identification and modelling of each street segment under investigation, modelling and determining street air pollution were initiated by using the semi-empirical approach proposed by Gualtieri and Tartaglia (1998). The data used for determining air pollution in the proposed approach is the number and the speed of vehicles achieved from the GIS-based multi-agent traffic micro simulation approach, wind direction, wind speed, solar radiation, air temperature and building heights.

Our preliminary work in this area indicates that agent technology can significantly help designers and decision makers in this context. Further efforts will be made on expanding the algorithm to other GIS applications.

REFERENCES

Braubach, L., Pokahr, A., Krempels, K. H. and Winfried Lamersdorf, W., 2004. Deployment of distributed multi-agent Systems, Proc. Fifth International Workshop on Engineering Societies in the Agents World, Eds., Marie-Pierre Gleizes and Andrea Omicini and Franco Zambonelli, Toulouse, France, 20-22 October 2004.

DePaul, F. T. and Sheil, C. M. 1986. Measurements of wind velocities in a street canyon. Atmospheric Environment. 3,455-459.

Gualtieri, G. and Tartaglia, M. 1998. Predicting urban traffic air pollution: A GIS framework, Transpn Res.-D, 3(5), pp. 329-336

Hanna, R. S., Briggs, A. G. and Hosker Jr, P. R., 1982. Handbook on Atmospheric Diffusion. Technical Information Center, Blacksburg, Virginia, U.S.A.

Horling, B., Lesser, V., Vincent, R., 2000. Multi-agent system simulation framework, Proc. 16th IMACS World Congress 2000 on Scientific Computation, Applied Mathematics and Simulation, 21-25 August, Lausanne, Switzerland.

Kesting, A., Treiber, M. and Helbing, D. 2007. MOBIL – A general lane-changing model for car-following models, Transportation Research Record: Journal of the Transportation Research Board, Volume 1999/2007, pp. 86-94.

Nagel. K., 2004. Multi-agent transportation simulation (draft). http://www.vsp.tuberlin.de/archive/simarchive/papers/book/book.pdf.

Ossowski, S., Hern´andez, J., Iglesias, C., and Fern´andez, A., 2002. Engineering agent systems for decision support. In P. Tolksdorf;and Zambonelli, editors, Engineering Societies in an Agent World III, LNAI, pp. 234–274. Springer.

Schumacher, M. and Ossowski, S., 2006. The governing environment, volume 3830 of Lecture Notes in Artificial Intelligence, pp. 88–104. Springer Verlag.

Tartaglia, M., Giannone, A., Gualtieri, G. and Barbaro, A.. 1995. Development and validation of an urban street canyon model based on carbon-monoxide experimental data measured in Firenze. In Urban Transport and the Environment for the 21st Century, ed. L. J. Sucharov. Computational Mechanics Publications, Southampton.

Treiber, M., Kesting, A., and Helbing, D. 2006. Delays, inaccuracies and anticipation in microscopic traffic models. Physica A 360, pp. 71–88.

Zannetti, P., 1990. Air Pollution Modeling. Van Nostrand Reinhold, New York.