Agent based Emission Evaluation of Traffic in Dynamic City Models

Gideon D. P. A. Aschwanden¹, Tobias Wullschleger², Hanspeter Müller³, Gerhard Schmitt⁴
¹,²,³,⁴ Chair of Information Architecture ETH Zurich Switzerland
¹,²,³,⁴ http://www.ia.arch.ethz.ch
¹ aschwanden@arch.ethz.ch, ² wtobias@student.ethz.ch, ³ hamuelle@student.ethz.ch, ⁴ schmitt@arch.ethz.ch

Abstract. We present a simulation platform to evaluate procedurally generated 3d city models with a set of agents representing urban street actors and pedestrians towards greenhouse gas emissions from transportation. Our aim is to give architects and urban planners an empiric tool to analyze, predict and quantify traffic fluctuations over time, and define the number of occupants, individual traffic and public transport in a city. In this project we show that the allocation of functions within a city is an important factor for the appearance of traffic. The occupant’s decisions where they want to go are defined by the allocation of functions – and the distance defines the mode of transportation. We simulate the decision processes and gain information about the path, the mode of transportation, and the emissions they produce, and individual experiences like stress and effort. The autonomous driving cars are equipped with an acceleration based emission model allowing us to evaluate the impact of jammed streets on the emission of cars.

Keywords. Urban Planning; Multi-agent System; Generative City Model; Occupant Movement; Traffic Emission.

Motivation

Every urban planner has the aim to enhance urban systems to improve the efficiency and the quality of life for the inhabitants. Current planning methods are insufficient for the future needs created by increased pressure on the performance, the unprecedented size of cities and the constant change of urban configurations. The demand for simulations, incorporating different scales and interdependencies is increasing in order to evaluate and predict the impact of planning efforts. This project tries to show the effect of high level planning decisions about the allocation of functions and density, defined in a master plan, on the decision of people how to travel (with respect to pollutant emission generated on travel).

In the last century several planning patterns placed their emphasis on path optimization for cars and inflicted drastic changes on the city, which affected not just road users. A shift in the mindset has taken place, and humans have returned into the focus of attention. We regard the health and well being of people as the most important criteria for good
urban planning. To gain this information, social studies have to be conducted, making it an expensive, time-consuming effort. With the methods of artificial intelligence we are able to simulate the behavior of large crowds and receive empiric information. Still, artificially gained results have to be computed on the basis of real-world statistic data in order to obtain any planning relevance.

Introduction Method

This project uses the combination (Parish and Müller, 2001) of a generative city model and a set of agents. The generative city model allows the fast adjustment of the 3D representation of the city, like street layout and volumetry of each building, and also incorporates meta data, like function and size. This is feasible from the design phase to the prediction of the impact of interventions in an existing city. In a second stage we are using artificial intelligence to evaluate the city. The agents can be mobile (pedestrians, cars, buses etc.) or immobile (buildings, bus stations etc.).

The focus of this project lays on the pedestrian agents, the mode of transport they use and the implications this has on greenhouse gas emission. With the metadata of function, floor space etc. the system calculates the amount of people occupying each building (Aschwanden et al., 2009) and the flow in and out over time. The pedestrian agents are dividing this decision process into two parts. First they define the goal depending on preference and distance. In the second instance the mode of transport gets decided also according to distant and individual preferences (detailed elaboration in section Agents).

Requirements

**3D Model:** With the simulation focusing on the public and street space the 3D model of the city can be schematic, visible to the agent to avoid collision.

**Functional layer of the city:** Represented by a set of immobile agents the city’s semantic attribute about the function is generated directly by the grammar, including the size of the buildings.

**Street lanes:** Street users read the lanes to know where they are heading to (crossing) and what kind of street they are on (max speed).

**Control parameters:** Many parameters are very specific to a location and are very diverse why we only give a short list of adaptable parameters. Emission values (mg/m), acceleration rates (m/s2), capacity of buildings (m2/person x function), capacity of public transport (persons/bus), red light interval (s), minimal personal space standing or walking (m2/person), source of agents etc.

Agents

In our case agents are intelligent machines able to I) perceive their environment, II) make decisions according to an internal set of preferences and III) react in a dynamic system. The agents reevaluate their decisions constantly to react on their environment. Dynamic agents also represent the city’s physical and functional aspects. Each agent consists of a brain and a physical body with individual abilities. To interact we trained them to hear and emit sound, read and paint the ground, following lanes and track it in the brain, makes a decision and acts accordingly. The agents inform us constantly how they perceive the environment. In the last projects we showed that every agent produces empiric results (Aschwanden et al., 2008), about the city’s functional, physical and social structure. The urban agents, as an analytical tool, allow optimizing towards several aspects of the city, ranging from physical aspects, like width of the sidewalk to the semantic layer like allocations of functions within the urban fabric.
other objects with computer vision.

**Pedestrian Agents**

Pedestrian Agents are able to hear, see and read the ground and interact with other agents by emitting sound with a specific frequency perceptible to other agents. The hearing ability allows the pedestrian agents to distinguish different functions within the city and the state of other agents as different frequencies are emitted. The vision of the agent is used to avoid collision with other moving objects. The ability to read the ground allows the agent to understand where it walks and to adjust its parameters and habits. Along the way the agent draws a graph onto the terrain according to its experience, e.g. stress, exhaustion, decision, etc.

Decisions: The decision process is based on a probabilistic socio-statistical data (Schenk, 1995). An agent has a set of preferences for each function and measures its distance towards them. The inconsistency in this approach is reducing with the amount of agents used in the experiment. The combination of distance and preference data sets produces a decision. When reached the first Point Of Interest (POI) the agent is choosing a new one neglecting visited places. Two aspects influence the mode of travel. The measured distance of the chosen POI compared to the distance of the next bus station and the individual preference towards public transport, individual transport and walking.

**Public Transportation (Bus)**

**Street interaction:** Representing the public transport, the bus brings pedestrian agents from a station to another. The acceleration engine and emissions are similar to that used by the car agent (section below). The bus agent behaves like a car, slowing down into turns, braking for traffic lights or queuing up in car rows. The public transport agent only differs in maximum velocity and acceleration rates, which are lower, and taking a predefined path.

Processing Pedestrians: The public transport agent is using the bus station agent to know if the next station is occupied, i.e. it needs to stop, or not. An arrived bus agent allows the pedestrians to debark, check, if there is still capacity left, and allows more pedestrian agents to board until there are no more agents waiting or the capacity limit is reached. Traveling by bus, the pedestrian agent is constantly measuring its distance to the POI and indicates the bus agent to stop as soon as the measured value falls below a minimal distance value. The bus stops at the next bus station.

**Bus Station**

Interface between street traffic and crowd zone: Bus stations have the simple task to define the area where agents can board or debark the public transport agent. The bus station agent is passing the information if a pedestrian agent is waiting for the public transport agent.

**Individual Transport (car)**

Parameters: lane orientation, crossing decisions, distance computing to changes in lane disposition, distance computing to other agents, interactive acceleration values, emission values per acceleration range (mg/s)

Car control: Every car agent driving in a row is using the highest possible speed, defined by I) individual aspects like car type and the driver type, II) the minimum distance to break according to its current speed and distance to the agent ahead and III) getting on the best lane of all possible adjacent lanes regarding agent’s desires. (Hagemann, 2009) The minimum distance of two consecutively driving cars is related to the current velocity and, in this project, equals the overall stopping distance, expressed in meters or the time and consists of the reaction distance or time and the actual braking distance or time (Chandler and Herman, 1958). The agent constantly computes the distance between itself and the agents ahead. The reaction time and additional breaking distance deliver the minimum distance \(d_{\text{min}} \text{[m]}\), according to the current speed \(tz\), and the current distance \(d \text{[m]}\). Using the ratio \(d/d_{\text{min}}\)
we are able to evaluate different situations of agents following each other:

1. \( \frac{d}{d_{\text{min}}} > 1 \), states that the agent could accelerate, unless the maximum velocity, defined by the lane type, is reached.

2. \( \frac{d}{d_{\text{min}}} = 1 \), states that the agent is currently driving at ‘ideal distance’ for the current velocity. Permanently driving at this distance is not realistic, since oscillation occurs between leading and following cars. The acceleration and deceleration values in this narrow range around \( \frac{d}{d_{\text{min}}} = 1 \) are either +/- 0.25 m/s² (as used in VISSIM).

3. \( \frac{d}{d_{\text{min}}} < 1 \), states that the agent is currently driving too close and needs to decelerate. Distinguishing between moving and resting objects and a turn ahead.

4. \( \frac{d}{d_{\text{min}}} = \text{infinite} \), states that there is no car ahead and the car agent can accelerate with maximum acceleration rate till the maximum velocity defined by the lane type is reached.

Results: The car agent is able to find its way to a given POI through a city setup using the lane disposition and interacting with the other street using agents. The agent is reacting on changes in its surrounding by changing its acceleration value. This enables us to get every agent’s acceleration profile for a given period driving through a city setup. We evaluate the time driven at a certain instantaneous speed and acceleration interval and apply emission values from engine data to obtain an agent specific emission profile. We investigate to what extent changes in the street network, in the crossing setup with its traffic lights, in the disposition of public transport facilities as well as in the allocation of functions and in pedestrian movement influence the flux structure and therefore the emission profile of the traffic system of a given perimeter. The perimeter’s structure then can be modified in order to improve traffic efficiency and reduce emission peaks caused by inefficient flux structures. The perimeter’s dimension itself can range from a single crossing situation to a street block up to a whole district or a city.

Building Agent (POI)

Each building with a function is emitting a specific frequency understandable to the pedestrian agent. Building agents do the interaction of the city and its inhabitants. The building agent has a specific capacity according to the size of the building, location within the city (Aschwanden et al., 2009). With agents entering the building agent reacts, by

Figure 1
1) POI 100, blue paths 2) POI 200, red paths 3) POI 300, green path, 4) POI 120, white line and final destination.
Experiments

This part is organized in two parts, first we are validating the output of each individual agent as well as the interaction of multiple agents and in a second case we combine all agents in a macro case.

Validation and Prove of Concept

Decision process for different Points of Interest

Experiment setup: Agents placed on one line over three different POIs and a final POI below. The pedestrian agents start at deciding between the three middle POIs, drawing accordingly a blue, red or green line. As soon as they reach their goal, they go to point 4 and end.

Results: Each of the three POIs has a subjective popularity, but is statistically indifferent. Multiplied with the measured proximity, the pedestrian agent makes the decision by preferring the highest product. In Figure 1 we can see each agent drawing a line according to the chosen POI. The agents do prefer the closest POI, but not exclusively. In the middle are 3 POIs (1-3), around them different colors are visible, indicating the agents’ decision process before they get forced to go to 4) and end.

Decision process for different Modes of Transportation:

Experiment setup: In addition to the same setup as above (Decision process for different Points of Interest) the agents get the option to use public transport to get from their first goals (1,2,3) to their final one (4). We introduced a bus line with 3 bus stations (a-c). The agents are now drawing their decision about the mode of transportation, blue for walking and red if the distance is to big to walk. The bus path is colored from red (low loading) to yellow (high loading) or no color when empty.

Results: With each agent having an individual preference towards each mode of transport. The graphical output shows that the closer the next goal is, the more pedestrian agents decide to walk. The bus discharges then all of the agents at the station c) closest to 4).

Emission of cars according to traffic flow:

With the car agent we introduced an acceleration-based emission-computing model on an urban scale. The car agent’s speed is defined by the sum of all acceleration values. Pairing them with the engines specific emission data enables us to calculate the flux and emissions. Emissions are heavily defined by the acceleration pattern, using the average speed.
can lead to differences up to factor two. Wiedemann (1991) showed that the reaction of drivers is only triggered when a certain level of distance or acceleration difference is reached. Hoefs proved that cars are oscillating around an equilibrium, which leads to congestion waves in the traffic flow. Our system is able to simulate the behavior of cars. According to the utility rate of the street these congestion effects, with the correlating acceleration patterns (see (Kerner and Konhäuser, 1993)), lead to a collapse of the flow itself and to higher emissions. As a representative for pollutants emitted by car agents in this project we use the CO emissions for a first approach in calculating emissions of different city setups.

Acceleration Profile: According to emission values available in (Cernuschi et al., 1995), we use five acceleration classes and six speed intervals for acceleration and emission mapping:

high deceleration: $< -2.0 \text{ km/h} \text{ s}^{-1}$
($< -0.56 \text{ m/s}^2$) \hspace{1cm} (1)

low deceleration: $-2.0 \text{ km/h} \text{ s}^{-1}$ to $-0.5 \text{ km/h} \text{ s}^{-1}$
($-0.56 \text{ m/s}^2$ to $-0.14 \text{ m/s}^2$) \hspace{1cm} (2)

constant speed: $-0.5 \text{ km/h} \text{ s}^{-1}$ to $0.5 \text{ km/h} \text{ s}^{-1}$
($-0.14 \text{ m/s}^2$ to $0.14 \text{ m/s}^2$) \hspace{1cm} (3)

low acceleration: $0.5 \text{ km/h} \text{ s}^{-1}$ to $2.0 \text{ km/h} \text{ s}^{-1}$
($0.14 \text{ m/s}^2$ to $0.56 \text{ m/s}^2$) \hspace{1cm} (4)

high acceleration: $> 2.0 \text{ km/h} \text{ s}^{-1}$
($> 0.56 \text{ m/s}^2$) \hspace{1cm} (5)

The uniform speed intervals range from 0 to 60 km/h, as the defined maximum velocity in this project’s setup is set to 60 km/h (16.5 m/s). The values for steady state at 0 km/h are computed separately with 22 mg/sec CO.

Current emission per car agent [mg CO/sec]: Detecting the current acceleration class and speed interval the car agent is currently driving at, enables us to compute the current emission value [mg CO].

Average emission per car agent [g CO/m]: The car agent sums up the time driven at a specific acceleration class with the associated emission [mg/s CO] (see table below) to compute the total emission [g CO]. The total amount of emissions the car agent has emitted so far is divided by the total distance covered, yields the average emission for every agent. The car agents’ average emission values therefore can be compared with respect to their path taken through a city setup.

Experiment setup: Two symmetric circles intersecting twice, differing only in the number of cars (Fig. 3). The amount of agents on the high-density (HD)

<table>
<thead>
<tr>
<th>CO [mg/sec]</th>
<th>high deceleration</th>
<th>low deceleration</th>
<th>constant speed</th>
<th>low acceleration</th>
<th>high acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10 km/h</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td>10 - 20 km/h</td>
<td>39</td>
<td>37</td>
<td>48</td>
<td>46</td>
<td>48</td>
</tr>
<tr>
<td>20 - 30 km/h</td>
<td>45</td>
<td>41</td>
<td>58</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td>30 - 40 km/h</td>
<td>50</td>
<td>50</td>
<td>68</td>
<td>76</td>
<td>78</td>
</tr>
<tr>
<td>40 - 50 km/h</td>
<td>55</td>
<td>58</td>
<td>78</td>
<td>90</td>
<td>92</td>
</tr>
<tr>
<td>50 - 60 km/h</td>
<td>59</td>
<td>68</td>
<td>83</td>
<td>108</td>
<td>109</td>
</tr>
</tbody>
</table>

Figure 3
Agent/Lane setup on low density (LD) and high-density loop (HD).
loop is 10 times as large as on the low-density (LD) loop. The loop intersections’ priorities are regulated by a traffic light with a cycle of 70sec.

Results: The acceleration profile for both, low and high-density loops are shown in Figure 4 left. Significant differences are visible between sections LD1/LD2 (ability to free drive at maximum speed (green periods)) and HD1/HD2 (stop and go in congestion situation (alternating acceleration (blue) and deceleration (red) appearing as purple period)). Figure 4, middle) shows larger instantaneous emission values for the low density loop than for the large density loop, resulting from the temporary ability to free drive at maximum speed on the low density loop causing larger emissions while accelerating to and within higher speed intervals. Despite this fact, the average emission values shown in Figure 4, right) in the high density loop are larger than in the low-density loop. Taking into account the acceleration profile for both loops, the impact of accelerating and decelerating, even at low rates, without covering significant amounts of distance and emitting at the steady state with no distance covered at all for longer time, dramatically increases the average emission per agent.

Macro Case

Experiment setup: We compare two cities (Fig. 5), different in the allocation of functions. In case A we grouped all similar functions, in case B each function is distributed homogeneously over the city. We used 700 Pedestrian agents, deciding between 40 different POIs. Two bus lines with 4 buses, serving 3 and 5 bus stations. There are up to 400 cars on the roads simultaneously, with a total of up to 8000 cars having passed through the perimeter in an hour.

Table 1
Emission and distance data per setup obtained after 75'000 frames (52 min).

<table>
<thead>
<tr>
<th>Agents:</th>
<th>5 (LD)</th>
<th>50 (HD)</th>
<th>10 (LD)</th>
<th>100 (HD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>total emissions [g CO]</td>
<td>676.812</td>
<td>3'816.860</td>
<td>1'232.613</td>
<td>6'187.761</td>
</tr>
<tr>
<td>total distance [km]</td>
<td>105.644</td>
<td>294.658</td>
<td>181.1</td>
<td>262.645</td>
</tr>
<tr>
<td>av. emissions [mg CO/m]</td>
<td>6.41</td>
<td>12.95</td>
<td>6.81</td>
<td>23.56</td>
</tr>
<tr>
<td>av. distance [m]</td>
<td>21'129</td>
<td>5'893</td>
<td>18'110</td>
<td>2'626</td>
</tr>
</tbody>
</table>

Figure 5
Left: Concentrated allocation of functions. Right: Homogenous allocation of functions.
Results: A no-POI setup was used as reference setup (Fig. 6). The car agent chooses its path randomly before leaving the setup again after 300 sec. Figure 6 shows the acceleration pattern over the whole area. Since the perimeter was on full load, i.e. permanently entered by car agents if enough space available, the acceleration and instantaneous emission profiles are most of all determined by the street and traffic lights setup and, therefore, not differing significantly between the different sets of POI distribution.

In an ideal setup we would have only green streets, indicating a constant speed without any acceleration. Several accelerations and decelerations are coming from slowing down in front of turns and redlights. We see already that some streets are only used in one direction or barely at all and others are suspect to congestion (indicated by magenta). Major differences between different POI setups (allocation of functions) are visible for the average emissions per car as shown in Figure 7 and by the values listed in Table 2.

![Figure 6](image1.png)

**Figure 6**
Top: acceleration distribution (no POI).

<table>
<thead>
<tr>
<th>agent data per setup</th>
<th>1) total no. cars passed through</th>
<th>2) total emissions [g CO]</th>
<th>3) total distance [km]</th>
<th>4) av. emission [mg CO/m]</th>
<th>5) av. distance per car [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) no POI</td>
<td>3839</td>
<td>40596.066</td>
<td>3530.646</td>
<td>11.5</td>
<td>919.7</td>
</tr>
<tr>
<td>b) POI mono</td>
<td>6376</td>
<td>28333.073</td>
<td>1861.635</td>
<td>15.2</td>
<td>292.0</td>
</tr>
<tr>
<td>c) POI poly</td>
<td>8085</td>
<td>21236.419</td>
<td>1773.285</td>
<td>12.0</td>
<td>219.3</td>
</tr>
</tbody>
</table>

![Figure 7](image2.png)

**Figure 7**
Left: average emissions POI concentrated allocation of functions, Right: average emissions POI homogenous allocation of functions.
The maps (Figure 8) show the mode of transportation each pedestrian is using to reach their goal. Blue indicates that the pedestrians are walking red indicates that they are heading for a bus station. We can see that when the functions and amenities are homogeneously distributed pedestrians actually prefer to walk instead of using public transport.

**Discussion & Conclusion**

Cities are complex entities shaped by a variety of forces and actors. We elaborated on the decision process and emission derived from the allocation of functions and proved that this has a major impact. The car agent, with his acceleration based emission model, is working on an urban scale allowing us to evaluate different street layouts. This, in combination with the allocation of functions, is a first step for a sustainable indicator of a city’s traffic network. We are also able to detect critical, inefficient and highly pollutant flux sections within the city layout and different design proposals.

We are considering the well being of people as the most important indicator for a city. This constitutes of several aspects stress and health. Pedestrians walking several short distances within a day are reducing stress and increases health of each individual. Therefore we are looking at the city as a gym, exercising the people and enable them to live a healthy life. The distance a person is willing to walk is varying a lot; the allocation of functions is therefore a major factor. A factor controlled by governmental institutions.

This project also shows the integration research from different field. According to Bratton (2009) half of the architect and urban planners should focus on the development of software for a better utilization of the existing infrastructure. As an architect and planner I see the integration of existing, proven simulation methods and software tools as the most promising way forward.

**References**


Cernuschi, S., Giugliano, M., Cemin, A. and Giovannini, I 1995, 'Modal analysis of vehicle emission factors Facteurs d’Émission modaux des véhicules', *Science*


