

# **Representing the road infrastructure in Open Traffic**

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## **Abstract**

In this paper we focus on the design of network objects for all types of assignment methods, varying from macroscopic assignments to micro simulation models. The basic idea is that the model environment should allow the simulation of traffic at multiple scales, based on standardized data formats. We derive the data requirements from an analysis of driving behaviour. Apart from the functional requirements, we propose a data format that aligns with to an existing international standard for geo-information, i.e. CityGML (Geographical Markup Language for city and landscape models).

Based on the requirement analysis we present a shortlist of objects and their characteristics that should be part of the description of the road infrastructure in simulation models. These objects have been implemented in the Open Source traffic and transportation model environment “Open Traffic”. Open Traffic offers the utility to transform the road infrastructure into logical networks for traffic simulation and assignment at various scales.

## **Keywords**

Microscopic simulation, network design, traffic model, model design, driver behaviour

# 1 Introduction

For evaluating, designing and planning of traffic facilities and measures, traffic simulation packages are the de facto tools for consultants, policy makers and researchers. However, available commercial simulation packages do not always offer the desired workflow and flexibility for academic research. In many cases researchers resort to designing and building their own dedicated models, without an intrinsic incentive (or the practical means) to make the results available for the public domain. To make things worse, a substantial part of these efforts pertains to rebuilding basic functionality and in many respects “reinventing the wheel”. This is not just a problem affecting the research community but one that adversely affects the entire traffic simulation community, and frustrates the development of traffic simulation in general. To address this problem, an open source approach initiative, OpenTraffic, is being developed as a collaborative effort of Queensland University of Technology, National Institute of Informatics and Technical University of Delft. The OpenTraffic simulation framework enables the collaboration of academics from different geographic areas and disciplines within the traffic domain to work together, and to contribute to a specific topic of interest ranging from travel choice behaviour to car following, and from response to ITS to activity planning.

Specifically, attention is provided to the software architecture. The modular approach enables users of the software to focus on their area of interest, whereas other functional modules can be regarded as black boxes. Attention is paid to a standardization of data inputs and outputs for traffic simulations. This will allow the sharing of data with many of the existing (commercial) simulation packages.

In this paper we focus on the design of network objects for all types of assignment methods, varying from macroscopic assignments to micro simulation models. The basic idea is that the model environment should allow the simulation of traffic at multiple scales, varying from macroscopic to detailed microscopic simulations. We focus on micro simulation because it requires the most complex description of a network. Networks for other types of assignments can be derived from the simulation network.

While the majority of the simulation models considers traffic that shows lane discipline and disregards lateral behaviour within a lane, we provide a framework that also enables the implementation of a simulation model with “shared usage of lanes or space”. Examples are:

- Mixed use of lanes by cars, mopeds and bicycles;
- Traffic lacking lane discipline;
- Shared space

The next section provides an overview of driving behaviour, and aims to detect which elements of the road infrastructure are essential for the simulation of traffic. We regard both longitudinal and lateral driving behaviour, both at freeways and within urban areas.

## 2 Taxonomy of driving behaviour and micro simulation

Traffic simulation models represent driving behaviour by means of mathematical models. These mathematical models identify the main elements that represent

longitudinal and lateral behaviour. The driving task can be structured in a strategic level (planning of a trip), a tactical level (manoeuvring: interactions with other traffic and the road system) and a control level (automatic action patterns) [1]. In this paper the driving task from a tactical level is regarded.

Driving at a tactical level distinguishes:

- Guidance over the available infrastructure;
- Guidance of vehicles around other moving objects.

With respect to the vehicle interactions, longitudinal and lateral subtasks are distinguished. Whereas the longitudinal interactions play an important role in the formation and propagation of congestion, the lateral driving tasks also have a significant impact on traffic flows [1]. We distinguish the roadway subtasks (choosing a lane, speed choices) and the vehicle subtasks (car following, merging, lane changing, gap acceptance).

External conditions may have a significant impact on driving behaviour and traffic flows. With respect to weather conditions, both rain, snow and fog do reduce road capacity significantly. Research on the influence of weather mainly focusses on longitudinal driving behaviour. In case of rain drivers tend to increase their headways. Emergency situations and evacuations appear to have an influence on driving behaviour, but its impact is merely based on assumptions and deductions.

To simulate driving behaviour, the impact of both the infrastructure and vehicle interactions need to be modelled by mathematical equations. In order to be able to provide a generic network structure for the modelling of driving behaviour, section 2 provides an overview of the main determinants that affect driving behaviour. A summary of the relevant network objects from this analysis is presented in Section 3. The implementation of these objects in the network module of OpenTraffic is shown in section 4. This paper closes with conclusions and future work.

## **2.1 Driving behaviour with lane discipline: longitudinal behaviour**

### **2.1.1 Longitudinal behaviour: vehicle interactions**

Several mathematical models describe both the longitudinal and lateral driving behaviour and their interactions. In order to implement driving behaviour in a modelling framework, we first identify the elements that are currently present in car following and lane-changing models and analyse the methods, parameters and variables.

A survey of car-following models reveals the following behavioural approaches.

1. 'Drivers reacting continuously': stimulus response and safety distance models
  - Vehicles react on their 'leading' vehicle and base their behaviour on.
    - Relative speed to leader;
    - Relative distance to leader;
    - Desired distance to leader.
  - Multi-anticipative models require the same information for multiple 'leaders'
2. Discrete behaviour: 'Action point' models

- Vehicles react on their ‘leading’ vehicle and base their behaviour on thresholds:
  - Minimum and maximum borders of the desired following distance;
  - Minimum and maximum borders for relative speed differences.

The car following models are expressed in equations. For a modular software environment, the parameters and expressions can be programmed in separate modules. However, the methods (or ‘routines’) describing driving behaviour do need a standardized set of input and output variables (interface) so that the module can be called by other methods without changing the structure of the program.

For car-following behaviour the information that is basically needed for vehicle interactions is:

- The actual state of ‘current’ and ‘leading’ vehicle(s)
  - type of vehicle
  - driver
  - position,
  - speed,
  - acceleration
- Drivers:
  - Reaction time;
  - A flexible list of parameters for driving behaviour models, such as:
    - A desired car following distance: ‘save or comfortable distance to avoid a collision’ in addition to a minimal stopping distance (at  $v=0$ );
    - Desired acceleration and deceleration rates;
- Vehicle characteristics:
  - Length, weight and height;
  - Vehicle dynamics: such as maximum speed, maximum acceleration and deceleration, drag and inertia
- Roads
  - Speed limit

### 2.1.2 Longitudinal behaviour: roadway physics

Besides the vehicle interactions, longitudinal behaviour is influenced by roadway characteristics. The majority of scientific research focusses on freeways: in case there is no leading vehicle, longitudinal behaviour will be governed by speed limits and the drivers’ desired speed. Specifically in urban areas, the roadway characteristics play an important role for determining the longitudinal behaviour. This section investigates the impact of the roadway on speed behaviour and as a result lists the main variables and objects for simulation models.

In addition to the speed limits and the drivers’ desired speed, the actual choice of speed will be determined by implicit speed limits that occur in case of:

- Curves of a road and turning movements at junctions;
- Nearing a junction with conflicting traffic. Depending on the visibility distance (distance from the junction where a driver can notice opposing traffic) and conflicting traffic drivers may need to slow down or, in case of traffic lights, come to a stop;
- Variations in gradients of the road;

- Narrow space with small margins between the ‘available’ width of a road/lane and the width of the vehicle;

For roadway physics the information that is basically needed is:

- Road and lane geometry
  - curvature,
  - width of lanes,
  - road gradient
- Junction geometry
  - Stop lines
  - Conflict areas
  - Turning movements (curves)
  - Visibility of the other arms of a junction

### **2.1.3 Longitudinal behaviour: interactions of roadway physics and vehicles**

Specifically at intersections, the longitudinal behaviour will be influenced by conflicts with opposing traffic. The actual behaviour depends on priority rules, in combination with opposing traffic and available gaps.

On roads with two or more lanes, the speed of an overtaking vehicle can be influenced by the width of the vehicle that is being overtaken and the remaining width (i.e. narrow lanes at road works). The same accounts for relatively narrow roads with opposing traffic and without a median.

For interactions of roadway physics and vehicles, the information that is basically needed is:

- Road and lane geometry
  - cross section geometry: median and total width of the driving lanes
- Identification of:
  - opposing vehicles or
  - the vehicle that is being overtaken
- At a junction: entering vehicle and identification of conflicting vehicles
- Junction geometry
  - Points of conflict and their characteristics (entering and exiting lanes)

## **2.2 Driving behaviour with lane discipline: lateral behaviour**

Lateral behaviour in simulation models is mainly reflected by lane changing and gap acceptance behaviour. Lane changes may be induced by roadway physics, for instance when leaving a freeway or making a turn at a junction. If there is no reason for mandatory lane change, a driver changes lanes if that lane provides better traffic conditions.

### **2.2.1 Lateral behaviour: vehicle interactions**

A lane change is desirable when speed advantages can be gained. The desirability depends on speed and distance characteristics of the lead and subject vehicle. The acceptance of gaps at the destination lane is a second factor that influences lane change decisions. We distinguish the lead gap and the lag gap that should meet minimum requirements. In these situations the following element need to be defined in the model:

- Characteristics of subject and surrounding vehicles (downstream and upstream)
  - Position at lanes
  - Vehicle length
  - Speed
  - Acceleration
  - Making or preparing a lane change

### **2.2.2 Lateral behaviour: roadway physics**

The mandatory lane changes are induced by the routing plan of the driver and the road configurations. If a driver has to make an intended turn, there will be a desire to move to that lane. This desire will increase when the distance towards the turn decreases.

The geometry of the lanes and the information signs are relevant with regards to the driver behaviour:

- Road and lane geometry:
  - Number of lanes;
  - Restrictions of lane usage;
  - Allowed turning movement;
  - Road marking along indicating allowed and prohibited lane changes.
- Traffic signs
  - Signs showing the distance to and information of nearing turns
- In car navigation
  - Lane directions and distance to turn

### **2.2.3 Lateral behaviour: roadway physics and vehicle interactions**

The combination of driver characteristics, surrounding vehicles and roadway design will determine lane changing behaviour.

At merges traffic behaviour is characterized by two phenomena, named relaxation and synchronization [2]. It expresses the behaviour of merging drivers who synchronize their speed with vehicles at the adjacent lane in order to align with a gap, and temporarily accept smaller time headways. This necessitates the recognition of merging lanes in a traffic model network.

In case of narrow lanes, the width (and length) of vehicles leading vehicles may have an impact on lane choice: in case of large trucks there may be only limited space and drivers may hesitate or decide not to overtake.

- Road and lane geometry:
  - Width of lanes;
  - Hard shoulder lanes
  - On-ramps and merging area
- Vehicle characteristics:
  - Width, length

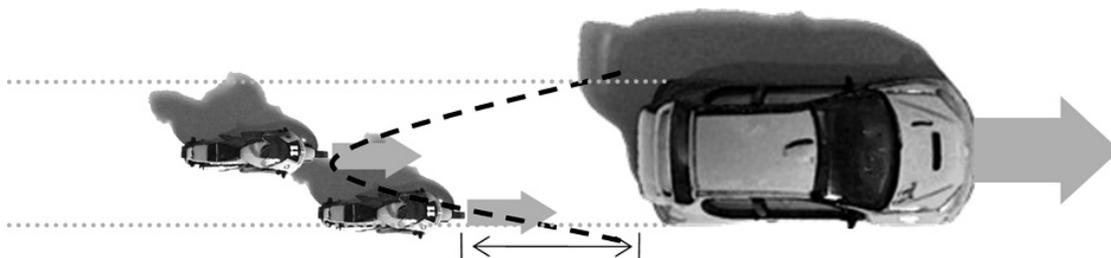
## **2.3 Driving behaviour with mixed traffic**

For urban situations or driving behaviour with low lane discipline or mixed traffic, even more detail may be needed to simulate traffic. Examples are:

- Roads with combined usage by a mix of vehicles, mopeds and bicycles;
- Impact of parked cars at the edge of a road;

- Pedestrian crossings when vehicle behaviour is influenced by crossing pedestrians.

Literature describing shared lane or road usage in simulation models appears shows that these models require more detail for the description of movements. We provide a short overview of studies where this topic is being explored. The interaction of motorcycles and cars is object of study in [3]. The article describes the elements contributing to the driving patterns of motorcycles and develops three mathematical models to depict these key elements. A particularly difference in behaviour is the fact that a motorcycle can swerve easily to avoid a collision if the leading vehicle brakes suddenly, by using the clearances beside the preceding vehicles. Figure 1 shows the interaction of longitudinal and lateral position and its impact on following distance. The model that is estimated to describe such behaviour requires the size of vehicle near the path of the motorcycle and the lateral distance to the ready-to-overtake position.



**Figure 1: example of mixed traffic showing interaction of lateral and longitudinal positions [3]**

Describing this behaviour, requires that the network provides information on both the lateral position of a vehicle, the size of the vehicle (width and length) and the road space between the vehicle and the curbs.

Another study [4] analyses the lane change and overtaking behaviour of vehicles under mixed traffic conditions and finds that the shoulder condition has some influence of rate of acceleration of a vehicle type.

Apart from the road cross section, [5] shows that changes on driver behaviour (both on speed and on lateral position) are induced only by cross-sections and geometric elements and do not depend on the roadside configurations (for instance trees). Moreover, drivers do not change their behaviour when a barrier is present or not and, thus, when trees are not protected. With respect to the cross section configuration of the road, the main effects are:

- the shoulder on the right side spurs drivers to adopt higher speeds and to choose a lateral position which is further from the road axis
- the driver adopts a higher speed on the less demanding geometric elements and “cuts” the curves moving towards the centre of the road on the left curve and towards the right roadside on the right curves
- Speeds at the sharp right curves are significantly higher than that at the sharp left curves.
- Changes in lateral position appear at the start of a guardrail. For example [5] shows that when trees with a guardrail were introduced, drivers chose a

position which was moved toward the centre of the road (12 cm) compared to that adopted in the preceding section.

For interactions of roadway physics and vehicles, the information that is basically needed is:

median and total

### 3 Synopsis: road layout in simulation models

From the previous section we retrieve the following information to represent the road infrastructure in simulation models:

- Road signs
  - Speed limits (signs)
  - Signs showing the distance to, and information about nearing turns
- Road and lane geometry
  - road gradient;
  - detailed representation of the road geometry (curves)
  - number of lanes;
  - width per lane;
  - restrictions on lane usage;
  - cross section geometry: presence of a median, representation of barriers, hard shoulder lanes and berms
  - allowed turning movement(s) by lane;
  - road marking along, indicating allowed and prohibited lane changes.
  - on-ramps and merging area
- Junction geometry
  - Stop and yield lines
  - Turning movements (curves)
  - Visibility from the entering road
  - Points of conflict and their characteristics (entering and exiting lanes)

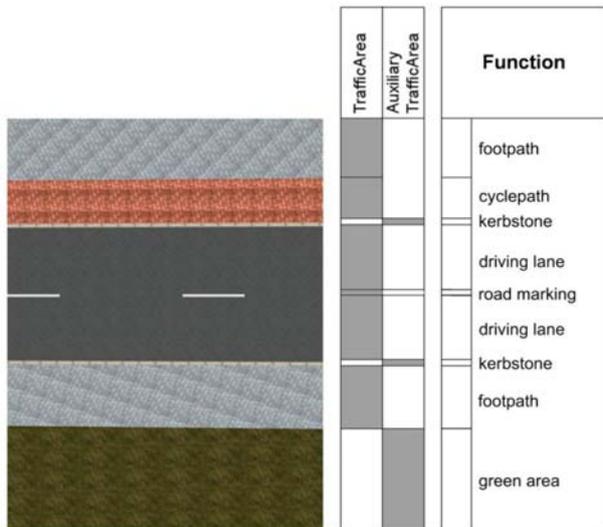
### 4 Design of the road infrastructure in Open Traffic

The design of network objects should be based on the requirements from the analysis in the preceding sections, but also on the availability of data. Currently, in many of simulation applications (such as Vissim or Paramics) the data structures used for input and output do not adhere to common data formats. In order to improve the exchange and reuse of data, we propose a data architecture for the physical input data of fixed objects in traffic and transportation models that is:

- In accordance with commonly accepted geographic database formats and definitions;
- Capable to provide all data requirements for multi scale assignment models.

To this end we propose to align to an international standard, i.e. the standard established by the Open Geospatial Consortium (OGC) for 3D city and landscape models, called CityGML [5]. The data model CityGML offers several Levels of

Detail (LOD) to support applications at different scales with the same data. The LOD concept of CityGML appears suitable to handle geographical data at different scales in transportation and traffic models. Such an approach where different levels of detail are provided, offers a solution for the potential stumbling block of using GIS databases, namely that they contain too much detail, particularly in cases of large areas (cities or regions) [6].



**Figure 2: example of a Cross Section profile of a road (source: [7])**

## 4.1 Road infrastructure: the main objects

In the Open Traffic the road infrastructure data objects are designed in accordance with the CityGML approach. Basically, we adhere as much as possible to the topology in reality. Figure 2 for instance, shows the elements of the cross section of a road, that all can be functional in a traffic simulation model. The road marking provides the rules for lane changing, whereas the varying driving lane and footpath provide the infrastructure for movement of different modes. Such representation is implemented in Open Traffic by means of the following object design.

### *Links and nodes*

The road network starts with a node and directional link objects. The nodes are basically used if roads join or split (for instance in case of junctions or merges) and traffic encounters ‘conflict areas’. The geometry of the roads is enhanced by *vertices* and *curves* between these vertices. Every road object has a ‘from’ and a ‘to’ node.

### *Cross sections*

Every link has at least one cross section object at the start of the link. This cross section object describes the cross section profile of a road from that point onwards. If the cross section profile of a road changes, a second cross section object is linked to the link object at that specific point.

Every cross section object carries the following objects and variables:

- The offset of the cross section from the centre line of the link;
- The relative distance of the cross section from the start of the link;

- A list of objects describing the cross section elements, such as the driving lane and hard shoulder lanes, the median, the kerbstone, footpath and the berms.

#### *Cross section elements*

A cross section element describes its function and topology. The elements are ordered, starting from the centre line of the link. The *width* of the element provides additional information for the road geometry. Every element carries a name that is linked with a *catalogue* of cross section elements, that is provided in the network description of Open Traffic. The catalogue describes its basic functions such as the allowed vehicles and its surface characteristics. This catalogue can be customized by adjusting elements or by adding new elements.

#### *Road markings along*

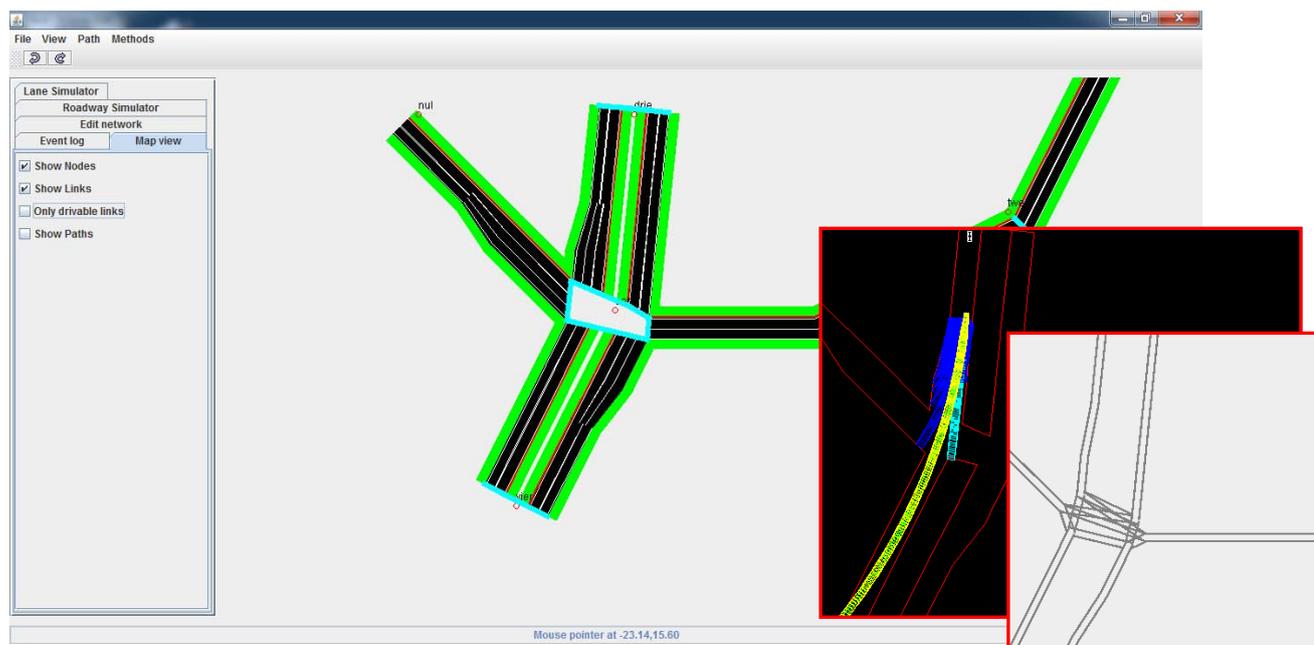
The elements that are drivable can have additional objects. An example is the road marking along that describes the lane changing rules for a road. Again, some templates for road markings are defined in an editable catalogue and can be connected to a cross section element.

#### *City furniture objects*

Additional objects that will be implemented in Open Traffic are detectors, stop and yield lines, traffic signs, variable message signs and other road side objects. All of them are defined as objects that can be connected to either a link object or to a cross section element.

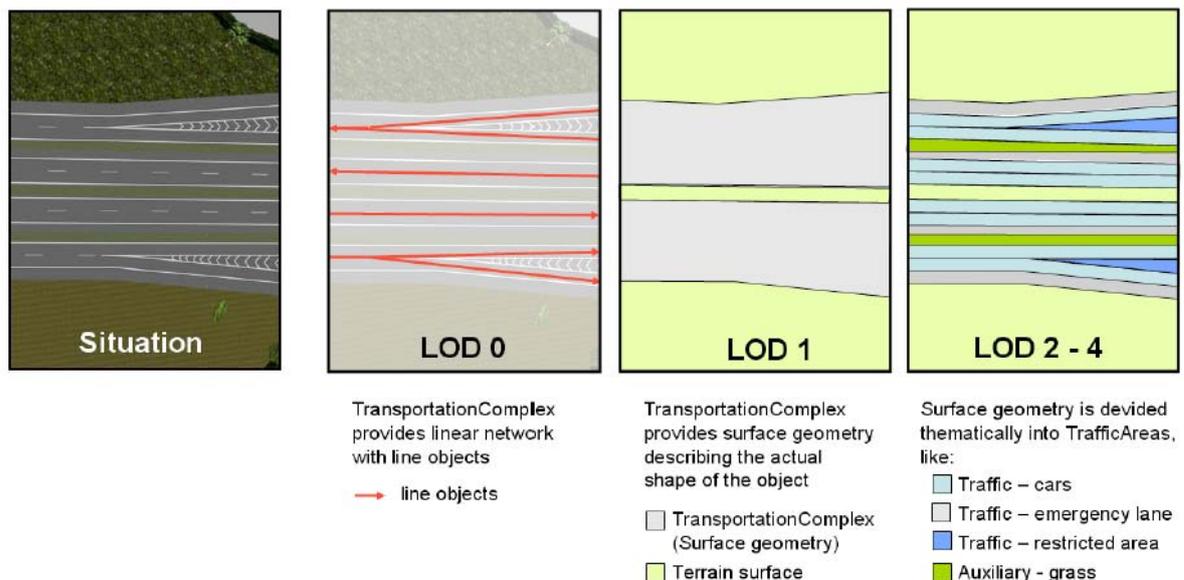
## 4.2 Creation of traffic simulation networks within Open Traffic

One of the objectives for Open Traffic is the ability to simulate traffic at multiple scales, varying from global to detailed. The network module of Open Traffic creates networks at varying levels of detail.



**Figure 3: Network creation in Open Traffic (full map view, roadway simulation and lane based network)**

Figure 3 shows a simple junction that is created with the afore mentioned network objects and includes the median (red), green areas, the driving lanes (black) with their road markings and the conflict area of a junction. This map shows the physical description of the road for or lane based simulations, and show some examples of other network formats that can automatically be derived, such as ‘roadway’, ‘lane’ and ‘link’ based networks. As is shown in Figure 4 this approach aligns with the levels of detail that are provided by CityGML.



**Figure 4: Transportation Levels of Detail in CityGML**

## 5 Conclusions and future work

In this paper we propose a uniform design for the modelling of the roadway infrastructure, allowing multiple levels of detail varying from macroscopic assignments to micro simulation models. The design is based on both the functional requirements derived from driving behaviour and the ambition to adhere to common data formats. We propose to align to CityGML, an international standard for geo-information.

Based on the requirement analysis we have made a shortlist of objects and their characteristics that should be part of the description of the road infrastructure in simulation models.

These objects have been implemented in the Open Source traffic and transportation model environment “Open Traffic”. Open Traffic offers the utility to transform the road infrastructure into logical networks for traffic simulation and assignment at various scales.

The next step in the development of Open Traffic is the modular implementation of assignment and simulation methods.

## Acknowledgements

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