INTELLIGENT TRANSPORTATION SYSTEMS:

LECTURE 8:
MICROSCOPIC SIMULATION MODELS
IN SUMO

Amnir Hadachi, PhD.
hadachi@ut.ee

Fall 2022
SUMO SIMULATOR MODEL
DEFINITION & HISTORY

DEFINITION:

SUMO, or Simulation of Urban Mobility, is an open-source simulator. It is designed for microscopic and multi-modal traffic simulation by DLR. It was created to provide researchers with a tool that will allow them to create and test their algorithms through simulation.

HISTORY:

- 2000: Beginning of the Development
- 2001: Implementation started
- End 2001: First release V0.1
- 2017: Eclipse Foundation project
- 2018: Release V1.0
- 2020: Future
- Release V1.8
Basic paradigms in SUMO:

Multimodal simulation
Basic paradigms in SUMO:

- Macroscopic
- Microscopic
- SubMicroscopic
- Mesoscopic
SUMO SIMULATOR MODEL
FUNDAMENTAL MODELS

GENERAL:

Traffic Microscopic simulation model

Micro-simulation models of traffic consist of different submodules:

- Car-following
- Lane-changing
- Intersection
- Emissions
CAR-FOLLOWING MODEL
SUMO SIMULATOR MODEL
CAR-FOLLOWING MODEL

**DEFINITION:** Car-following model

A car-following model is about controlling the driver’s or agent’s behavior concerning the preceding vehicle in the same lane. A car is considered following if it is constrained by a preceding vehicle, and keeping the desired speed will lead to an imminent crash.

**MOTIVATION:** Car-following model

- No accident
- The acceleration and braking deceleration should be realistic
- Dynamic situation handling, such as traffic lights or stops, etc.
- Reflecting driving styles
**SUMO SIMULATOR MODEL**

**CAR-FOLLOWING MODEL**

Illustration:

Time $t$
- Speed $v$
- Distance $x$

Time $t+T$
- Speed $v(t) + v(t+T) / 2T$

Stopping moment
- Speed $v(t) + v(t+T)$
- Distance $g_0$

Leader starts braking to stop at deceleration $b$
- Distance $x_{leader}$

Follower starts braking to stop at deceleration $b$
- Distance $x$

Mathematical equations:

- $v(t) + v(t+T)$
- $v_{leader} \cdot T - 1/2 \cdot b \cdot T^2$
- $v_{leader}^2 / 2b$
- $g_0$

Other equations:

- $v(t) + (v(t+T)) / 2T$
- $v(t) + v(t+T)^2 / 2b$
SUMO SIMULATOR MODEL
CAR-FOLLOWING MODEL

The model used based in SUMO a modified version of time/discrete and space/continues car following model by Krauß *1998

KEEP COLLISION-FREE BY CONTROLLING THE SAFE SPEED HENCE THE FORMULA DEFINED AS FOLLOWS:

\[ v_{safe}(t) = -\tau \cdot b + \sqrt{(\tau \cdot b)^2 + v_{leader}(t - 1)^2 + 2 \cdot b \cdot g_{leader}(t - 1)} \]

\( v_{leader} \) Speed of the leading vehicle at time \( t \)
\( g_{leader} \) Gap to the leading vehicle at time \( t \)
\( \tau \) The driver’s reaction time
\( b \) The deceleration function
NOW, WE MUST ENSURE THAT THE DRIVER CAN NOT ACCELERATE FASTER THAN IT CAN DO NOR THAT IT GETS FASTER THAN MAX VELOCITY. HENCE, WE DEFINE DESIRED OR WISHED VELOCITY AS FOLLOWS:

\[ v_{des}(t) = \min[v_{safe}(t), v(t - 1) + a, v_{max}] \]

- \( a \)  Maximum acceleration ability
- \( v(t) \)  Current velocity
- \( v_{max} \)  Maximum velocity
AS HUMANS, WE ARE NOT PERFECT IN RESPECTING RULES, AND THE MODEL OF KRAUß ALLOWS US TO INTRODUCE THIS BEHAVIOR IN THE SIMULATION AS FOLLOWS:

\[ v_{des}(t) = \min[v_{safe}(t), v(t - 1) + a, v_{max}] \]

\[ v(t + \Delta t) = \max[0, v_{des}(t) - r \cdot a \cdot \epsilon] \]

- \( a \): Maximum acceleration ability
- \( \epsilon \): Driver's imperfection, constant between \([0, 1]\)
- \( r \): Random number between \([0, 1]\)

SUMO SIMULATOR MODEL
CAR-FOLLOWING MODEL

TWO EXTENSIONS WERE ADDED TO THE ORIGINAL MODEL

1 APPLYING A DECAY IN THE ACCELERATION ABILITY

\[ a(v) = a(1 - \frac{v}{v_{\text{max}}}) \]

2 REDUCING DRIVER'S IMPERFECTION EFFECT

\[ v(t) = \max[0, v_{\text{dawdle}}(t)] \]

\[ v_{\text{dawdle}}(t) = \begin{cases} 
    v_{\text{des}}(t) \cdot \epsilon \cdot r & \text{if } v_{\text{des}}(t) < a(v_{\text{des}}(t)) \\
    v(t) - \epsilon \cdot r \cdot a(v_{\text{des}}(t)) & \text{Otherwise}
\end{cases} \]

SUMO SIMULATOR MODEL
CAR-FOLLOWING MODEL

The model used based on Gipps Model extended by Krauß

TO ENSURE COLLISION-FREE IN CASE OF COMPLEX NETWORK (E.G. OSM) THESE RULES ARE APPLIED:

• Adjust velocity to the Leader’s speed and keep a safe distance (over the next lanes)
• Adjust to the allowed speed in the next lane.
• When the vehicle is approaching an intersection and it has no right-of-way, compute two speeds, one in the case of passing through the intersection and another one for coming to a stop at the intersection. Store them. Let the intersection know the vehicle is approaching.
• Continue with the next lane along the route or stop if the seen lane lengths’ sum is larger than the braking distance.

SUMO SIMULATOR MODEL
LANE-CHANGING MODEL

**DEFINITION:** Lane-changing model

The lane-changing model regulates lane choice on multilane roads and adjusts the speed to execute the maneuver.
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

- **COMPUTING A VALID PATH THROUGH THE NETWORK**
- **EXAMINING ALL THE LANES ON THE CURRENTLY USED ROAD AND ALL FOLLOWING ROADS ON ITS ROUTE**
- **OCCUPANCY INFO IS COLLECTED**
- **BASED ON THE INFO COLLECTED, THE VEHICLE DECIDES TO MOVE TO A VALID LANE OR NOT**

A LANE THAT CAN BE USED FOR CONTINUING THE ROUTE WITHOUT CHANGING IT
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

- **Computing a valid path through the network**
- **Examining all the lanes on the currently used road and all following roads on its route**
- **Occupancy info is collected**
- **Based on the info collected, the vehicle decides to move to a valid lane or not**

Decision is formulated by also taking into account the distance needed for lane change defined as follows:

\[
d_{l_{c,veh}}(t) = \begin{cases} 
    v_{veh}(t) \cdot \alpha_1 + 2l_{veh} & \text{if } v_{veh}(t) \leq v_{thresh}(t) \\
    v_{veh}(t) \cdot \alpha_2 + 2l_{veh} & \text{Otherwise}
\end{cases}
\]

- \(v_{thresh}(t)\): Maximum acceleration ability
- \(v_{veh}(t)\): Threshold recriminating highway and urban behavior
- \(\alpha_1 \& \alpha_2\): Scaling factors
- \(l_{veh}\): Vehicle length
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

1. **Computing a valid path through the network**
2. **Examining all the lanes on the currently used road and all following roads on its route**
3. **Occupancy info is collected**
4. **Based on the info collected, the vehicle decides to move to a valid lane or not**
5. **The approach takes into account the occupancies of all detected lanes till the position where the route cannot be continued**
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

1. **Computing a valid path through the network**
2. **Examining all the lanes on the currently used road and all following roads on its route**
3. **Occupancy info is collected**
4. **Based on the info collected, the vehicle decides to move to a valid lane or not**
5. **The approach takes into account the occupancies of all detected lanes till the position where the route cannot be continued**
6. **This forces the simulated vehicles to change lanes at the end of queues on the current lane, preventing them from increasing congestion on the jammed lane.**
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

1. Computing a valid path through the network.
2. Examining all the lanes on the currently used road and all following roads on its route.
3. Occupancy info is collected.
4. Based on the info collected, the vehicle decides to move to a valid lane or not.
5. The approach takes into account the occupancies of all detected lanes till the position where the route cannot be continued.
6. This forces the simulated vehicles to change lanes at the end of queues on the current lane, preventing them from increasing congestion on the jammed lane.
7. The tactical part of lane-changing the speed is handled by defining a benefit score for changing lanes.
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

**BENEFIT SCORE IS DEFINED AS FOLLOWS:**

\[
b_{ln}(t) = \frac{[v_{pos}(t, l_{n}) - v_{pos}(t, l_{c})]}{v_{max}(l_{c})}
\]

- \(v_{pos}(t, l)\): Safe speed for driving on lane \(l\) at time \(t\)
- \(v_{max}(l)\): Maximum speed on lane \(l\)
- \(l_{c} \& l_{n}\): Refer to current lane and next lane
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

BENEFIT SCORE IS DEFINED AS FOLLOWS:

\[ b_{ln}(t) = \frac{v_{pos}(t, l_n) - v_{pos}(t, l_c)}{v_{max}(l_c)} \]

- \( v_{pos}(t, l) \): Safe speed for driving on lane \( l \) at time \( t \)
- \( v_{max}(l) \): Maximum speed on lane \( l \)
- \( l_c \) & \( l_n \): Refer to current lane and next lane

Suppose the situation does not allow the driver/agent to change lanes. In that case, a particular interaction is activated to enable communication and collect status with surrounding vehicles at the front and behind.
The implemented Lane-changing model in SUMO solves the problem following a set of steps:

- **Benefit Score is Defined as follows:**

- **Defining the Blocked/Blocking Status Using the Following Rules:**

\[
v_{\text{next}}(t) = \begin{cases} 
  v_{\text{decelerating}}(t) & \text{if blocking/blocked at own back and front} \\
  v_{\text{decelerating}}(t) & \text{if blocking/blocked at own front} \\
  v_{\text{accelerating}}(t) & \text{if blocking/blocked at own back}
\end{cases}
\]

\[
v_{\text{decelerate}}(t) = v_{cf}(t) + \frac{v_{\text{max}}(t)}{2}
\]

\[
v_{\text{accelerate}}(t) = v_{cf}(t) + \frac{v_{\text{min}}(t)}{2}
\]

- \(v_{cf}(t)\) The car-following speed including driver's imperfection
- \(v_{\text{max}}(l)\) The speed after a maximum possible acceleration
- \(v_{\text{min}}(t)\) The speed after a minimum possible deceleration
INTERSECTION MODEL
The intersection model determines the behavior of agents or vehicles at different intersections. The model considers the right-of-way rules, gap acceptance, and avoiding junction blockage.
SUMO SIMULATOR MODEL
LANE-CHANGING MODEL

IMPROVEMENT IS NEEDED

Therefore, additional rules should be added:

• Intersections without prioritization
• Prioritize:
  - Intersections with different directions of the prioritized road (e.g., straight, turning)
  - Unprioritized lanes with yield or stop signs
• Intersection controlled by traffic lights
SUMO SIMULATOR MODEL
LANE-CHANGING MODEL

IMPORTANT ASPECTS

The model requirements in SUMO for realistic intersection dynamics:
No deadlocks
No collision
Efficient use of intersection
Realistic acceptance gaps
Approaching unprioritized links without stopping
Qualitative dynamics independent of the simulation step length
SUMO SIMULATOR MODEL
LANE-CHANGING MODEL
SUMO SIMULATOR MODEL
LANE-CHANGING MODEL
The approaching vehicle informs all the intersection in its route within a range of 3000m.
SUMO SIMULATOR MODEL

LANE-CHANGING MODEL

ENTRY

EXIT

ENTRY

EXIT

EXIT

VEHICLE INFO
INTERSECTION OF THEIR ARRIVAL

ARRIVAL
The vehicle stops broadcasting to the intersection the moment it crosses its entry.
SUMO SIMULATOR MODEL

LANE-CHANGING MODEL

Make use of the car-following model
SUMO SIMULATOR MODEL
LANE-CHANGING MODEL

Make use of the car-following model

- Designate a leading vehicle
- Define the distance between the follower and the lead vehicle.
SUMO SIMULATOR MODEL

LANE-CHANGING MODEL

EXAMPLE:
SUMO SIMULATOR MODEL
LANE-CHANGING MODEL

EXAMPLE:
EXAMPLE:

\[ G = d_f - d_{leader} - L_{leader} - \text{minGap}(F) \]
EMISSIONS MODEL
SUMO SIMULATOR MODEL

EMISSIONS MODEL

DEFINITION: Emissions Model in SUMO

The emissions model in SUMO is based on two approaches:
- HBEFA (The Handbook Emission Factors for Road Transport ) model
- PHEMlight (Passenger Car and Heavy Duty Emission Model) Model
THE HBEFA is relying on a database counting information about different pollutants from vehicles. The ones used in SUMO are as follows:

- CO2
- CO
- HC
- NOx
- PMx
- Fuel consumption
- Electricity

Type of vehicles:
- Passenger cars
- Light vehicles
- Coaches
- City bus
- Motor cycles
- Heavy Goods vehicles
### SUMO Simulator Model

#### Emissions Model

**Sample of Database**

<table>
<thead>
<tr>
<th>Passenger Cars</th>
<th>HBEFA Subsegment</th>
<th>HBEFA Subsegment ID</th>
<th>Fleet Share 2022</th>
<th>Error CO2</th>
<th>Error CO</th>
<th>Error HC</th>
<th>Error FC</th>
<th>Error NOx</th>
<th>Error PM</th>
<th>Error FC_MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC_petrol_ECE</td>
<td>PC petrol &lt;ECE</td>
<td>111900</td>
<td>0.0332%</td>
<td>5.41%</td>
<td>26.38%</td>
<td>7.35%</td>
<td>5.41%</td>
<td>17.23%</td>
<td>66.33% + 3.07%</td>
<td>-</td>
</tr>
<tr>
<td>PC_petrol_ECE-15_00</td>
<td>PC petrol ECE-15'00</td>
<td>111901</td>
<td>0.0000%</td>
<td>5.41%</td>
<td>26.38%</td>
<td>7.36%</td>
<td>5.41%</td>
<td>17.23%</td>
<td>66.33% + 3.07%</td>
<td>-</td>
</tr>
<tr>
<td>PC_petrol_ECE-15_01_02</td>
<td>PC petrol ECE-15'01/02</td>
<td>111902</td>
<td>0.0000%</td>
<td>5.41%</td>
<td>26.38%</td>
<td>7.55%</td>
<td>5.41%</td>
<td>17.23%</td>
<td>66.33% + 3.07%</td>
<td>-</td>
</tr>
<tr>
<td>PC_petrol_ECE-15_03</td>
<td>PC petrol ECE-15'03</td>
<td>111903</td>
<td>0.0000%</td>
<td>5.41%</td>
<td>26.38%</td>
<td>7.41%</td>
<td>5.41%</td>
<td>16.92%</td>
<td>66.33% + 3.07%</td>
<td>-</td>
</tr>
<tr>
<td>PC_petrol_ECE-15_04</td>
<td>PC petrol ECE-15'04</td>
<td>111904</td>
<td>0.0180%</td>
<td>5.41%</td>
<td>26.05%</td>
<td>7.02%</td>
<td>5.41%</td>
<td>16.79%</td>
<td>66.33% + 3.07%</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light Vehicles</th>
<th>HBEFA Subsegment</th>
<th>HBEFA Subsegment ID</th>
<th>Fleet Share 2022</th>
<th>Error CO2</th>
<th>Error CO</th>
<th>Error HC</th>
<th>Error FC</th>
<th>Error NOx</th>
<th>Error PM</th>
<th>Error FC_MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCV_petrol_M+N+1-Conv &lt;1981</td>
<td>LCV petrol M+N+1-Conv &lt;1981</td>
<td>212100</td>
<td>0.0000%</td>
<td>6.51%</td>
<td>30.77%</td>
<td>10.23%</td>
<td>6.51%</td>
<td>29.31%</td>
<td>47.95% + 2.97%</td>
<td>-</td>
</tr>
<tr>
<td>LCV_petrol_M+N+1-Conv &gt;1981</td>
<td>LCV petrol M+N+1-Conv &gt;1981</td>
<td>212101</td>
<td>0.1697%</td>
<td>6.51%</td>
<td>30.77%</td>
<td>10.23%</td>
<td>6.51%</td>
<td>29.31%</td>
<td>47.95% + 2.97%</td>
<td>-</td>
</tr>
<tr>
<td>LCV_petrol_M+N+1-Euro-1</td>
<td>LCV petrol M+N+1-Euro-1</td>
<td>212110</td>
<td>0.0186%</td>
<td>6.52%</td>
<td>50.25%</td>
<td>29.38%</td>
<td>6.52%</td>
<td>12.67%</td>
<td>48.14% + 2.96%</td>
<td>-</td>
</tr>
<tr>
<td>LCV_petrol_M+N+1-3WCat 1987-1990</td>
<td>LCV petrol M+N+1-3WCat 1987-1990</td>
<td>212111</td>
<td>0.0000%</td>
<td>6.52%</td>
<td>50.25%</td>
<td>29.38%</td>
<td>6.52%</td>
<td>12.67%</td>
<td>48.14% + 2.96%</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>City Bus</th>
<th>HBEFA Subsegment</th>
<th>HBEFA Subsegment ID</th>
<th>Fleet Share 2022</th>
<th>Error CO2</th>
<th>Error CO</th>
<th>Error HC</th>
<th>Error FC</th>
<th>Error NOx</th>
<th>Error PM</th>
<th>Error FC_MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBus_Midi_P &lt;=15t_Euro-IV</td>
<td>UBus Midi &lt;=15t Euro-IV</td>
<td>717140</td>
<td>0.0000%</td>
<td>18.23%</td>
<td>17.77%</td>
<td>15.02%</td>
<td>18.23%</td>
<td>21.40%</td>
<td>18.52% + 15.91%</td>
<td>-</td>
</tr>
<tr>
<td>UBus_Midi_P &lt;=15t_Euro-V</td>
<td>UBus Midi &lt;=15t Euro-V</td>
<td>717150</td>
<td>0.0000%</td>
<td>18.88%</td>
<td>44.99%</td>
<td>8.75%</td>
<td>18.88%</td>
<td>18.80%</td>
<td>13.10% + 15.76%</td>
<td>-</td>
</tr>
<tr>
<td>UBus_Midi_P &lt;=15t_Euro-VI</td>
<td>UBus Midi &lt;=15t Euro-VI</td>
<td>717161</td>
<td>0.0000%</td>
<td>19.30%</td>
<td>22.57%</td>
<td>15.43%</td>
<td>19.30%</td>
<td>36.65%</td>
<td>38.60% + 16.91%</td>
<td>-</td>
</tr>
<tr>
<td>UBus_Midi_P &lt;=15t 50tones</td>
<td>UBus Midi &lt;=15t 50tones</td>
<td>727105</td>
<td>0.0000%</td>
<td>15.37%</td>
<td>11.90%</td>
<td>18.26%</td>
<td>15.37%</td>
<td>13.80%</td>
<td>9.69% + 14.90%</td>
<td>-</td>
</tr>
</tbody>
</table>
THE PHEMlight is a simplified version of PHEM simulation approach designed by the University of Graz. It focuses on simulating the vehicle's behavior via a set of parameters to provide basic emission factors to elaborate emission factors.

This is done by computing the power needed by the vehicle to move and complete the journey using this formula:
This is done by computing the power needed by the vehicle to move and complete the journey using this formula:

\[ P_e = \left( P_{\text{rolling resistance}} + P_{\text{air resistance}} + P_{\text{acceleration}} + P_{\text{road gradient}} \right) / \eta_{\text{gearbox}} \]

\[ P_R = (m_{\text{Vehicle}} + m_{\text{Load}}) \times g \times (F_{r_0} + F_{r_1} \times v + F_{r_4} \times v^4) \times v \]

\[ P_{\text{Air}} = (C_d \times A \times \frac{p}{2}) \times v^3 \]

\[ P_a = (m_{\text{Vehicle}} + m_{\text{Rotor}} + m_{\text{Load}}) \times a \times v \]

\[ P_{\text{grad}} = (m_{\text{Vehicle}} + m_{\text{Load}}) \times \text{Gradient} \times 0.01 \times v \]

\[ \eta_{\text{gearbox}} = 0.95 \text{ (average efficiency)} \]

Next, the value of power is used to look up the characteristic emission curves.
SUMO SIMULATOR MODEL
EMISSIONS MODEL

Summary:
THANK YOU FOR YOUR ATTENTION

— Intelligent Transportation Systems - MTAT.08.040 - Lecture 8