Multi-modal safety-optimized traffic management system using incident-informed rerouting and adaptive signal control: a SUMO application

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Motivation

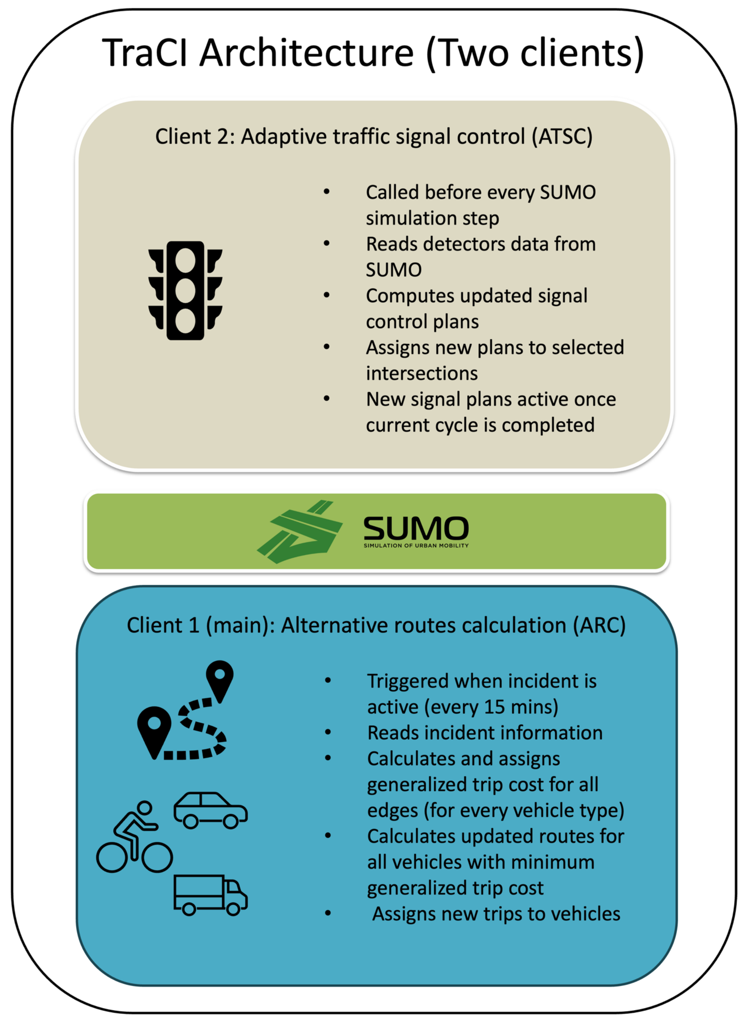
- Improve **safety** during unexpected hazardous **incidents** (accidents, extreme weather etc.) while maintaining good traffic performance
- Evaluate the role of adaptive traffic signals in presence of disturbed traffic patterns
- Protect vulnerable road users (e.g. two-wheelers)
- Provide safety-optimized routing based on vehicle type

Concept

- Propose **alternative routes** using a generalized trip cost considering safety distance from an incident location, traffic congestion and vehicle type
- Deploy a system in SUMO to test the effectiveness of safety-optimized alternative routing and adaptive signal control using a Max Pressure controller
- Part of **iDriving** platform focusing on roadway infrastructure management with innovative technologies for increased road safety

System Architecture

- Rerouting algorithm and adaptive signals (max pressure)
- Implemented with TraCI (2 clients) using Python & C++
- Rerouting in regular intervals for all vehicles using generalized trip cost values (In SUMO: using *traci.vehicle.rerouteEffort* after setting the custom edge costs with *traci.edge.setEffort* per vehicle type)



Generalized Trip Cost Function

Trip cost defined per edge considering:

- alerts characteristics (type, location, intensity, affected vehicle types)
- Safety distance from incident location
- Active work zones

$$f_z(v_z, \text{lev}, L_z, \text{veh}, \{b_{acc,i}, b_{mnt,i}, b_{w,i}\}\ \forall\ i)$$
$$= \beta_1 \frac{L_z}{v_z} \quad \text{Travel time cost}$$
$$+ \sum_i \left[\beta_2\, b_{acc,i}\, D_{acc}\, H_{acc}(\text{veh}, \text{lev}) \right. \quad \text{Penalty cost due to proximity to accident location}$$
$$\left. + \beta_3\, b_{mnt,i}\, H_{mnt}(\text{veh}, \text{lev}) + \beta_4\, b_{w,i}\ H_w(\text{veh}, \text{lev}) \right]_{\text{alert}_i}$$

Penalty cost due to maintenance or/and extreme weather alert

$$D_{acc} = \begin{cases} (M_d - d_a), \text{if } M_d \geq d_a \\ 0\ , \text{else} \end{cases}$$

Safety distance M_d around accident location to be avoided by vehicles

$$d_a = \sqrt{\left(e_{z_x} - l_x\right)^2 + \left(e_{z_y} - l_y\right)^2}$$

Distance of edge start from accident location

$$H_{inc} = b_{\text{veh}}\ \text{lev}, \qquad \forall\ inc \in \{acc, mnt, w\}$$

Incident intensity parameter per vehicle type

Max Pressure Signal Control

- Feedback-control law (Varaiya, P. 2013)
- Aims at balancing queues in controlled intersection by allocating the green light duration
- Not requiring network demand or future state
- Sense: Measure current link occupancy (O_i) and saturation flow (S_i)
- Calculate Pressure: Determine the "weight" of each stage based on active movements
- Allocate: Distribute the cycle's flexible green time

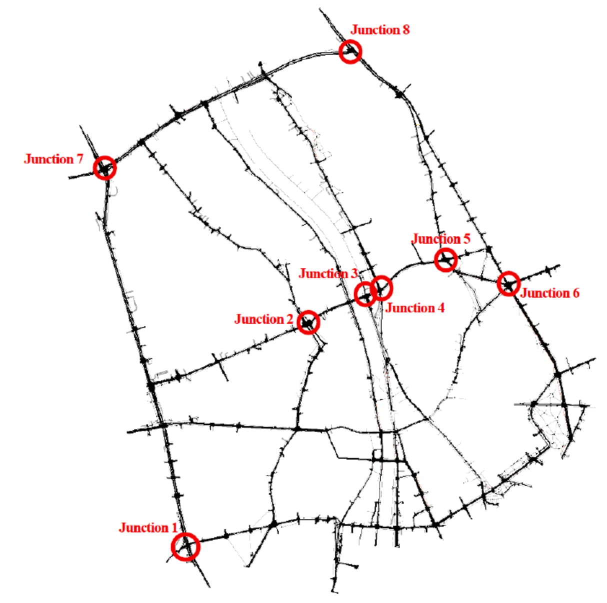
- Core formula:

$$G_j = \left(\frac{W_j}{\sum W}\right) * T_{\text{avail}} + T_{\min,j}$$

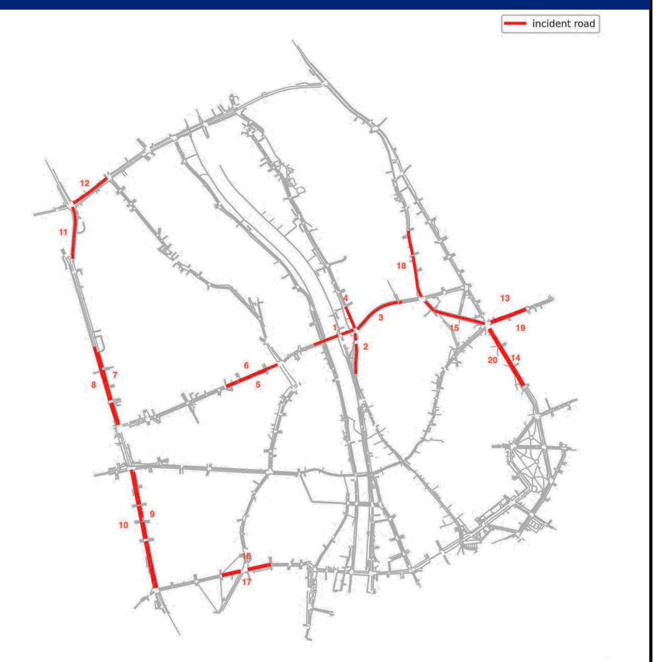
- G_j: Final green time for stage j
- W_j: Pressure of current stage j $(Demand\ * Capacity)$
- $\sum W$: The sum of pressures of all stages
- T_{avail}: Total assignable green time
- $T_{\min,j}$: The mandatory minimum green time for stage j

Case Study & Test Scenarios

- Network of city of Graz, Austria
- Demand adapted to match real traffic count data
- 1 h of simulation time
- Incident: accident
- Duration: 30 mins
- 10 replications per scenario (10 different seeds)
- Comparison with case with no-rerouting & pretimed signals

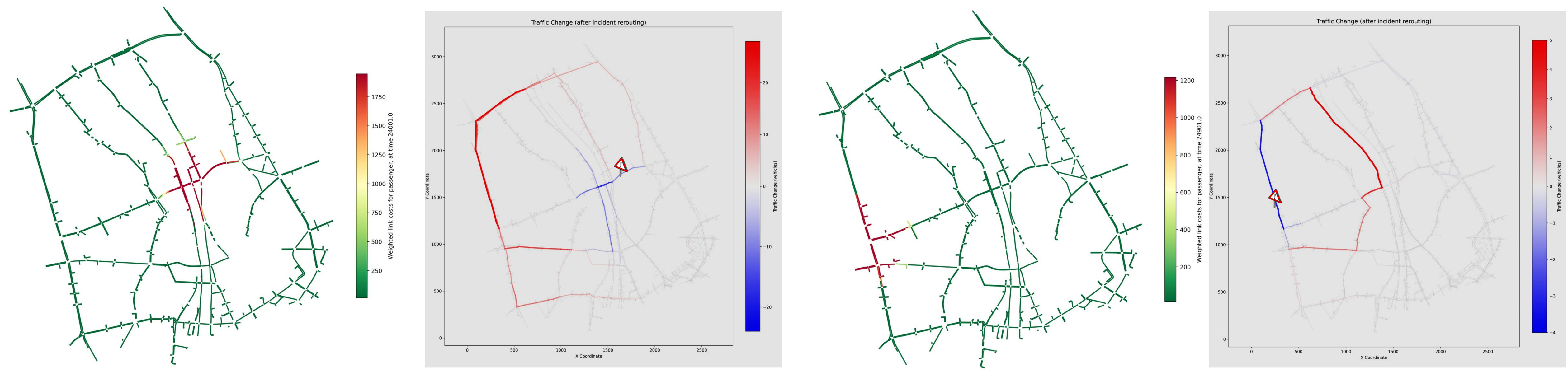


8 controlled intersections



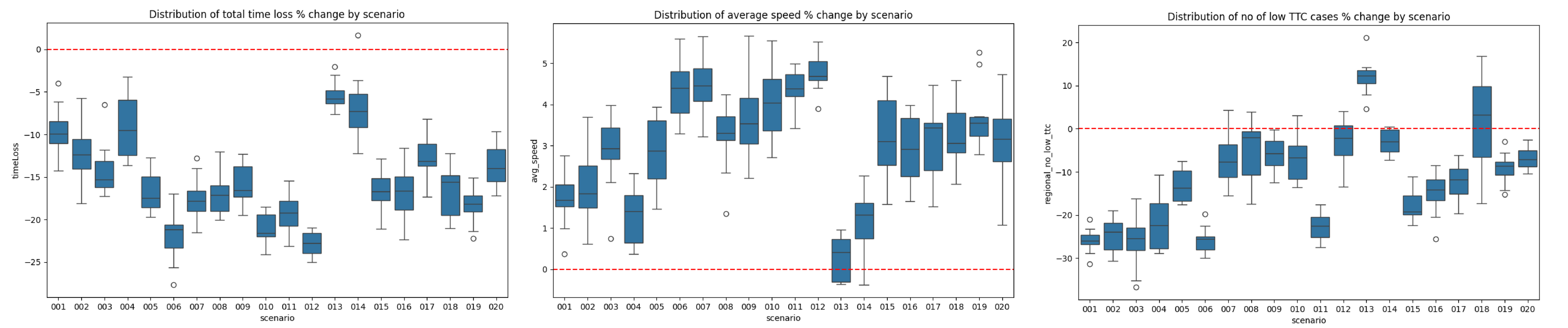
20 incident locations

Results



Scenario no. 3 Scenario no. 7

Heatmaps of generalized trip cost per link and road usage change for scenarios no. 3 (left) and 7 (right)



Percentile change in time loss (delay), average speed and number of low Time-To-Collision (TTC) events in the vicinity of the incident (< 400 m) compared to the do-nothing case (incident, no rerouting. no signals). Boxplots depict results for 10 replications (seeds) for each scenario.

Findings

- **Safety** and **traffic performance** improved in the vicinity of the localized incident in most scenarios tested:

- Rerouting algorithm reduced number of vehicles and risky vehicle interactions in the affected area
- Adaptive traffic signals helped reduce delay and increase average speed in the presence of modified traffic patterns

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