Security Level:

# Torino traffic flow optimization: Huawei ISAR adaptive system

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# Agenda

1. From raw data to simulation model
   a. Modeling of road network
   b. Modeling of traffic light programs
   c. Modeling of traffic flows
   d. Quality assessment of simulation model

2. Adaptive optimization of traffic flows
   a. Experimental setup
   b. Experimental comparison of trips waiting time
   c. Experimental comparison of CO2 emissions

3. Feedback session and next steps

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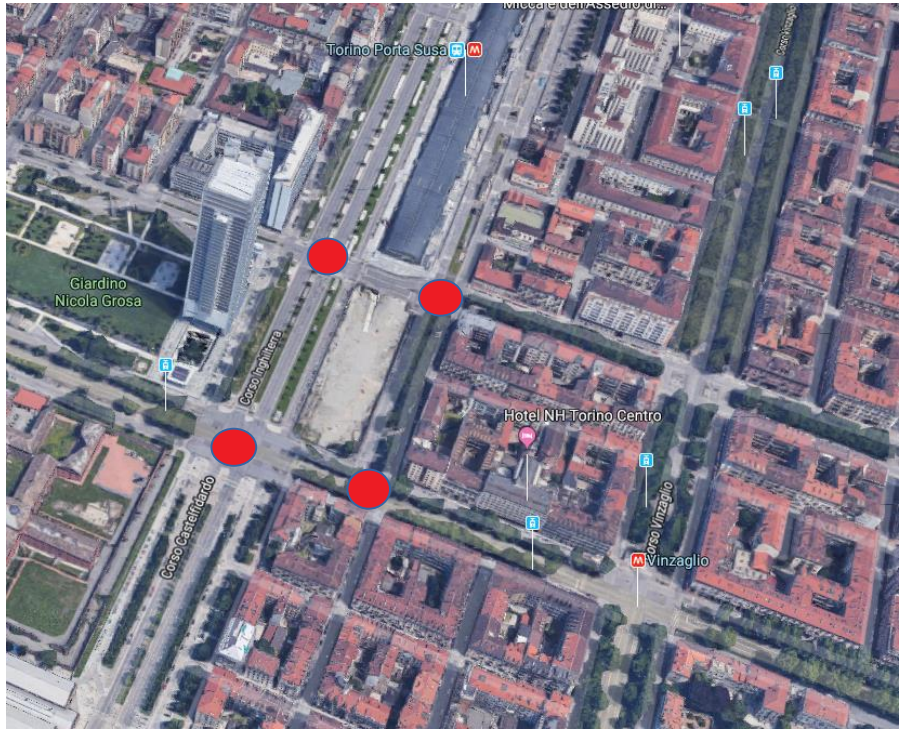
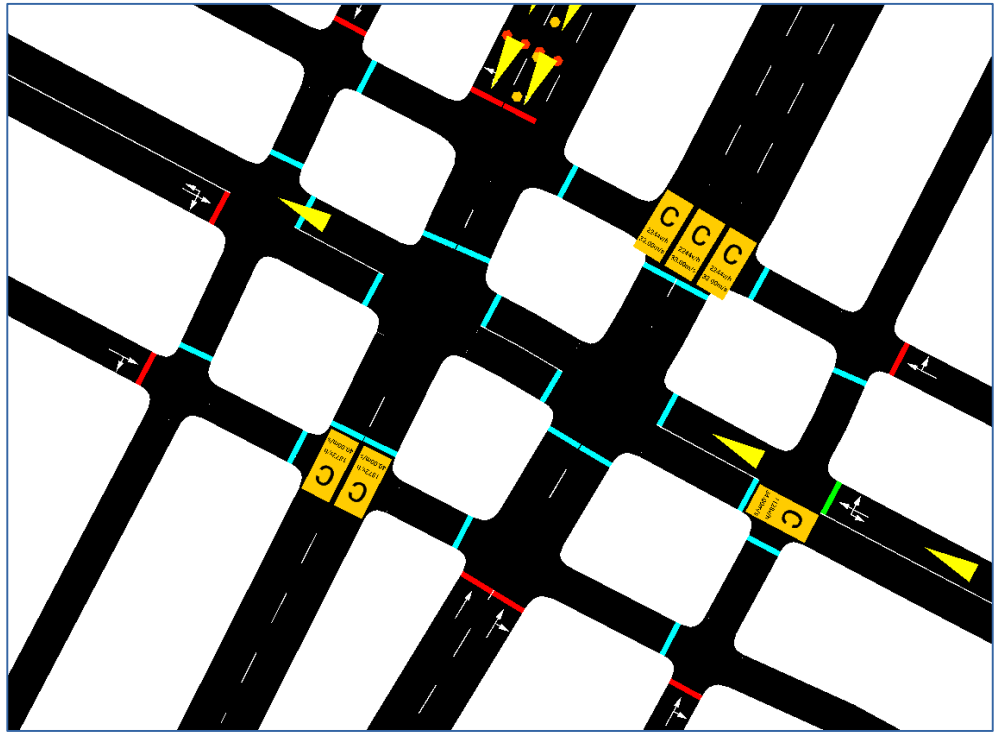
# Modeling of road network

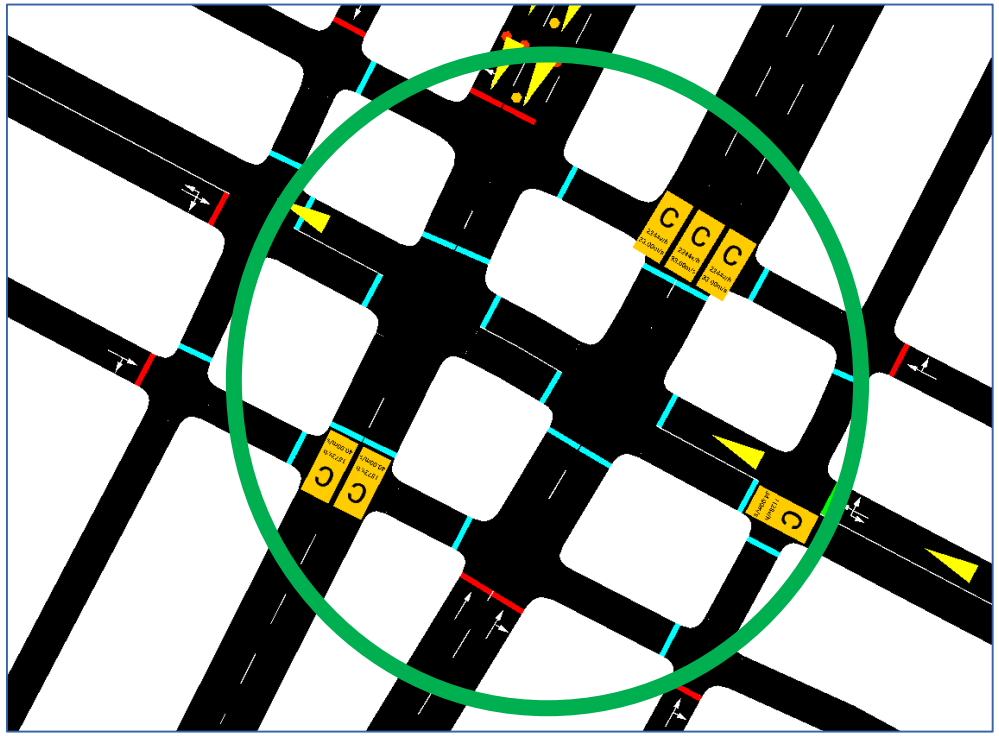
- Initial automated extraction of road network from OpenStreetMap

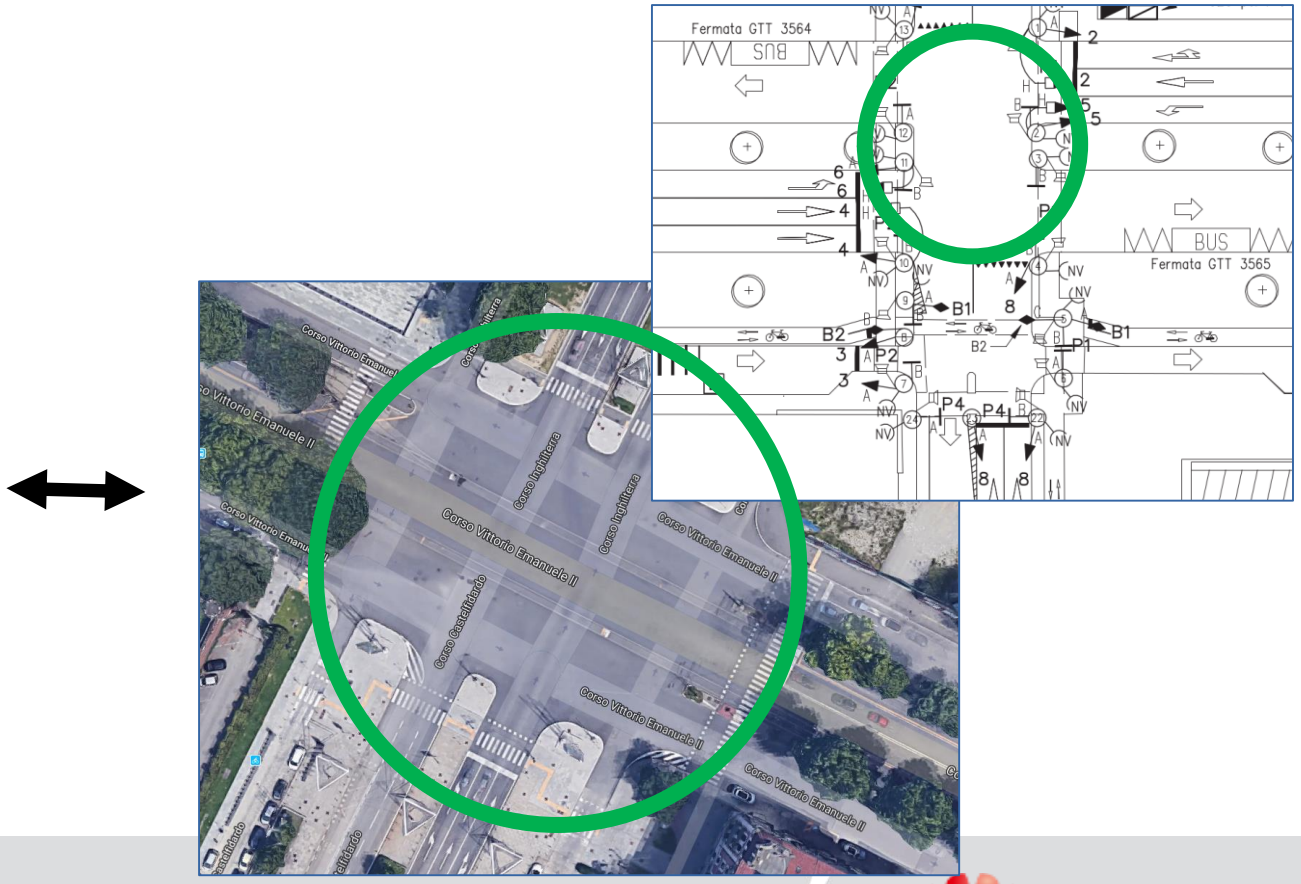


# Modeling of road network

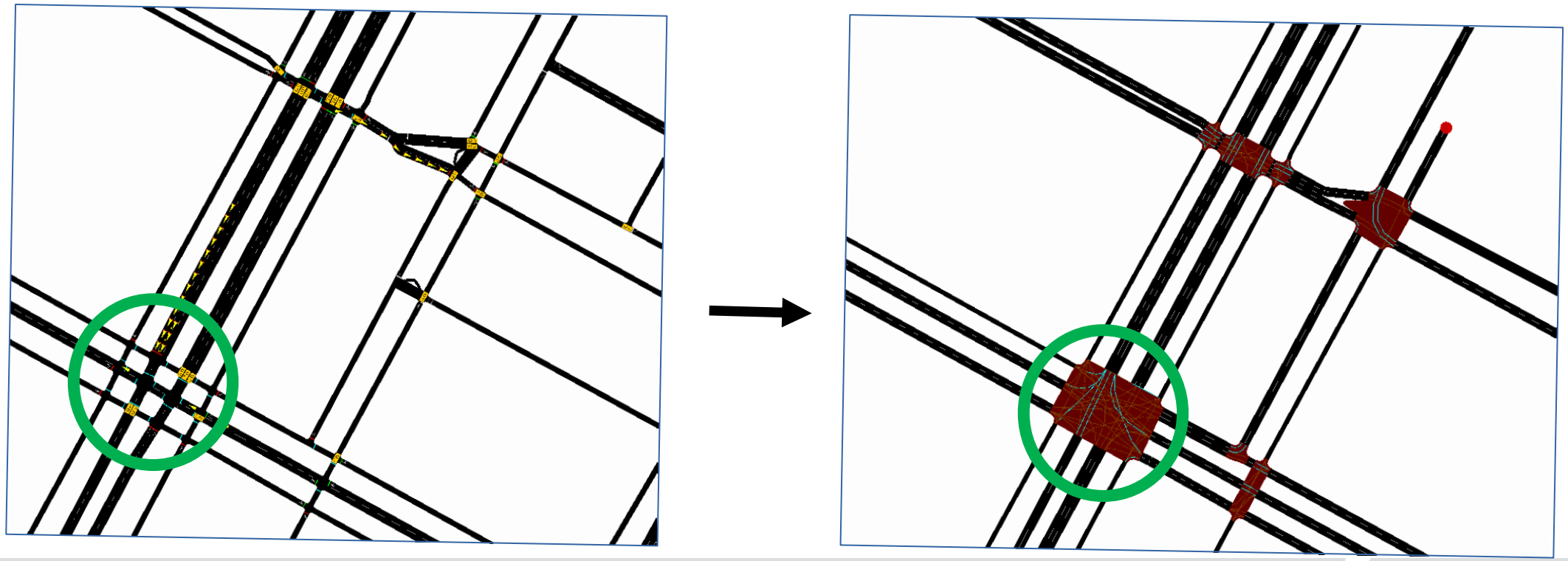
- Model errors: topology mismatches, wrong number of lanes, wrong junction connections, …





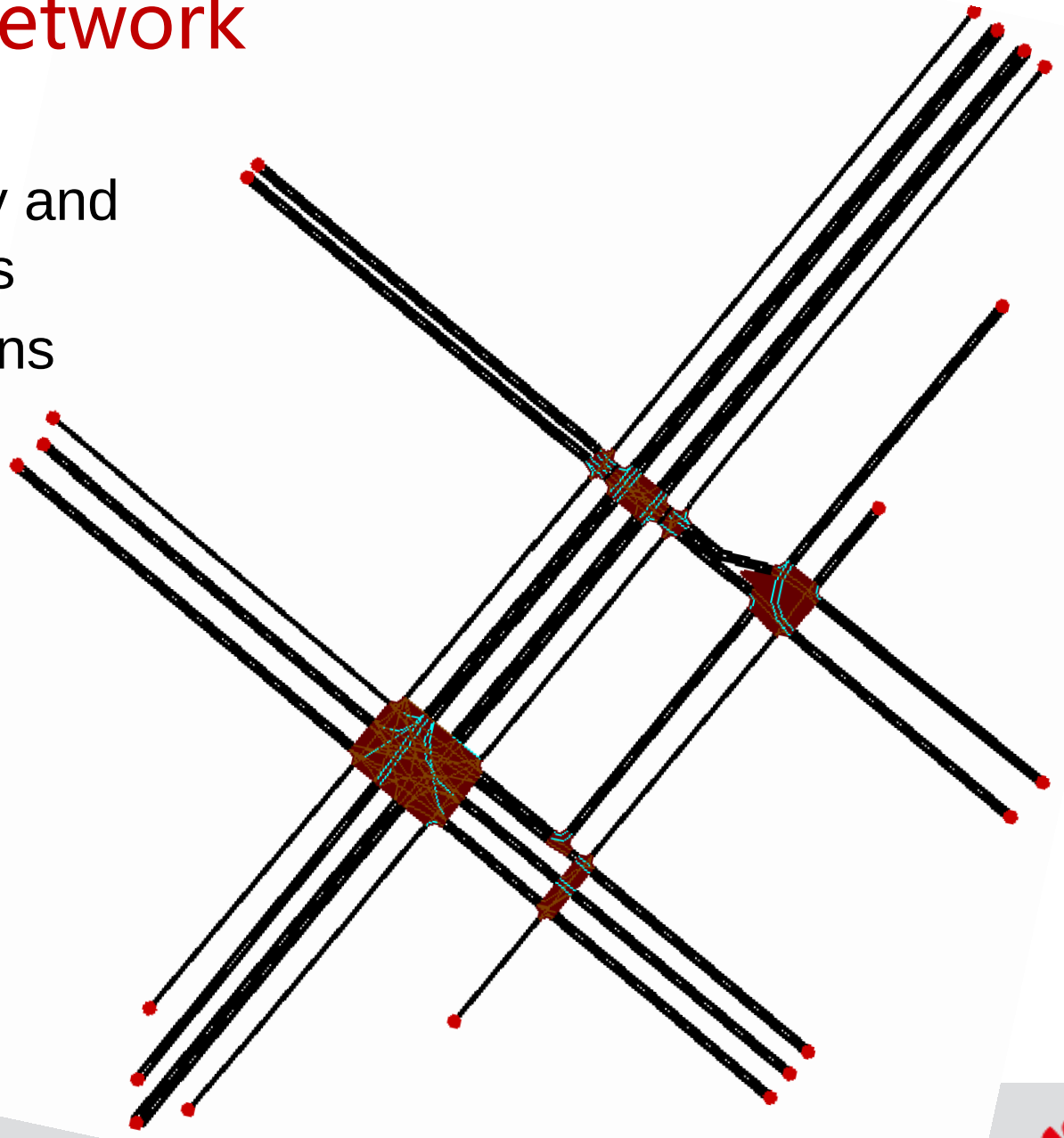
# Modeling of road network

- Several manual fixes applied: merging of edges, fixing of number of lanes, topology revision, cleanup of junction connections.



# Modeling of road network

- Revised network topology and edge-to-edge connections
- Stats: 40 edges, 7 junctions



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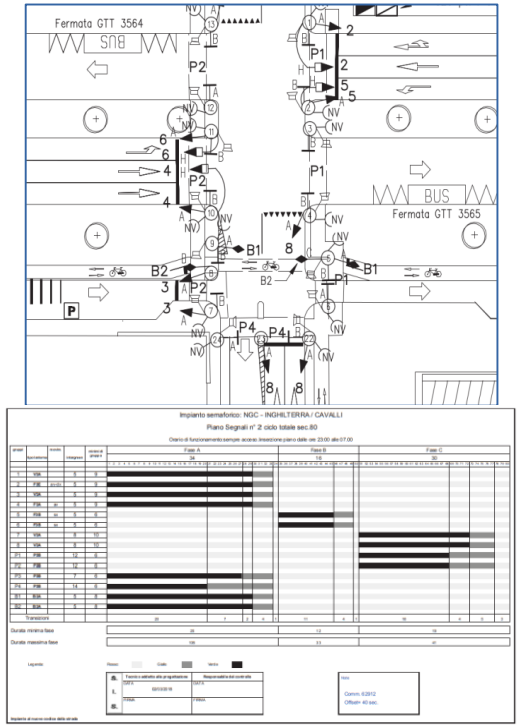
# Modeling of traffic light programs

- Documentation translated into tabular format for processing
- TLS programs extracted and reshaped in simulator format

Input documents (PDF)

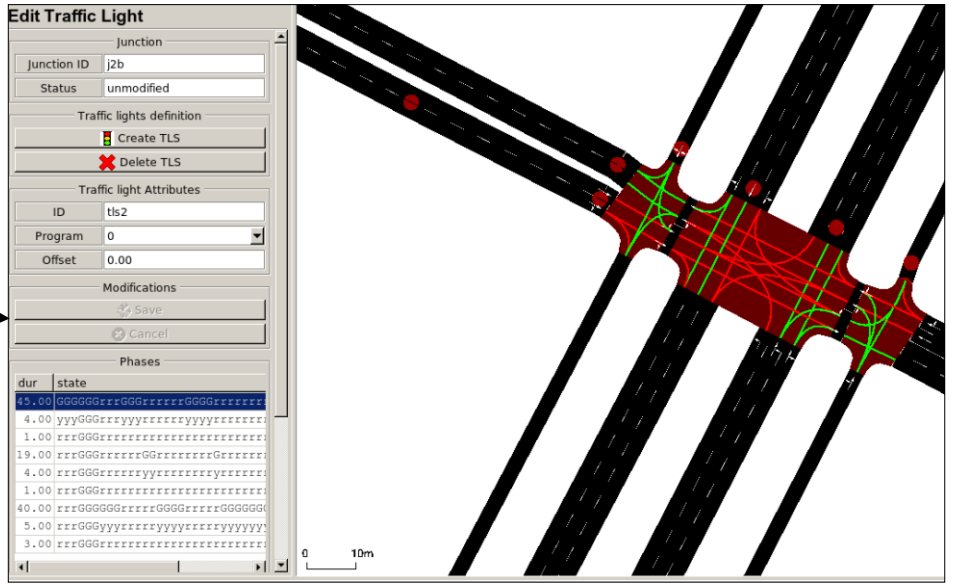



Tabular representation and processing

| phase_id | duration | s0 | s1 | s2 | s3 | s4 | s5 | s6 | s7 | s8 | s9 | s10 | s11 | s12 | tls_id |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 42 | G | G | G | r | r | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN | tls1 |
| A2 | 4 | G | y | y | r | r | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN | tls1 |
| A3 | 2 | G | r | r | r | r | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN | tls1 |
| B1 | 51 | G | r | r | G | G | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN | tls1 |
| B2 | 4 | G | r | r | y | y | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN | tls1 |
| B3 | 2 | G | r | r | r | r | NaN | NaN | NaN | NaN | NaN | NaN | NaN | NaN | tls1 |
| A1 | 45 | G | G | G | G | G | r | r | r | r | NaN | NaN | NaN | NaN | tls2 |
| A2 | 4 | G | y | y | y | y | r | r | r | r | NaN | NaN | NaN | NaN | tls2 |
| A3 | 1 | G | r | r | r | r | r | r | r | r | NaN | NaN | NaN | NaN | tls2 |
| B1 | 19 | G | r | r | r | r | G | G | r | r | NaN | NaN | NaN | NaN | tls2 |
| B2 | 4 | G | r | r | r | r | y | y | r | r | NaN | NaN | NaN | NaN | tls2 |
| B3 | 1 | G | r | r | r | r | r | r | r | r | NaN | NaN | NaN | NaN | tls2 |
| C1 | 40 | G | r | r | r | r | r | r | G | G | NaN | NaN | NaN | NaN | tls2 |
| C2 | 5 | G | r | r | r | r | r | r | y | y | NaN | NaN | NaN | NaN | tls2 |
| C3 | 3 | G | r | r | r | r | r | r | r | r | NaN | NaN | NaN | NaN | tls2 |

```
0 Processing tls tls1 phase A1 duration: 42 state: rrrGGGGrrGGG
1 Processing tls tls1 phase A2 duration:  4 state: rrryyyyrryyy
2 Processing tls tls1 phase A3 duration:  2 state: rrrrrrrrrrrr
3 Processing tls tls1 phase B1 duration: 51 state: GGGrrrrGGrrr
4 Processing tls tls1 phase B2 duration:  4 state: yyyrrrryyrrr
5 Processing tls tls1 phase B3 duration:  2 state: rrrrrrrrrrrr
```

Programs encoded in SUMO simulator format



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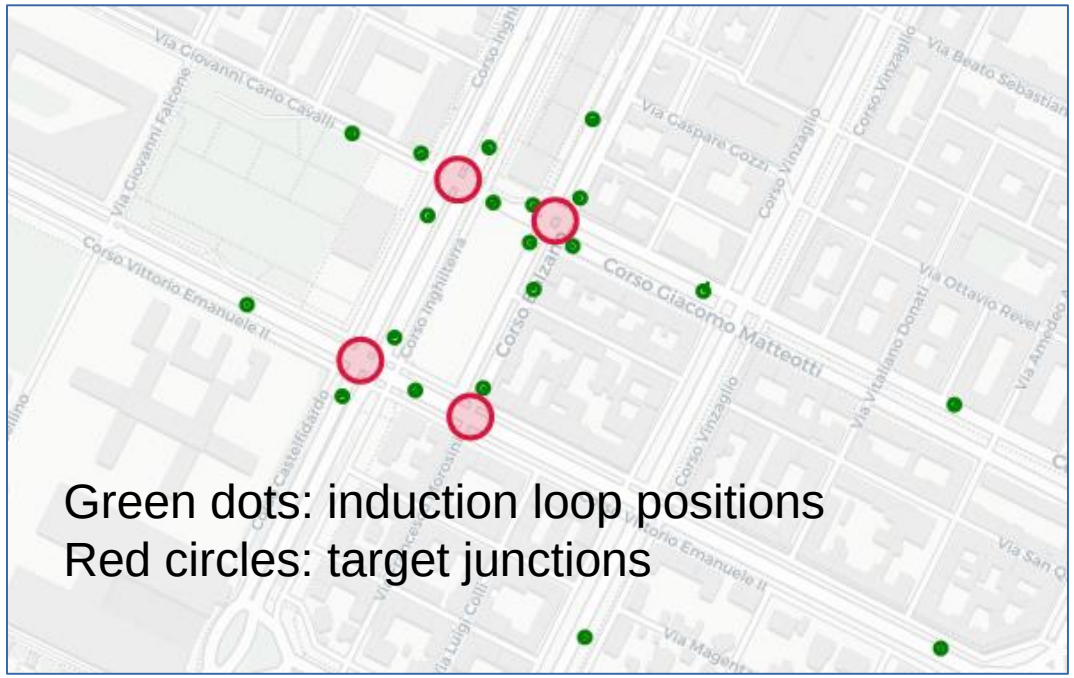
# Modeling of traffic flows: raw data

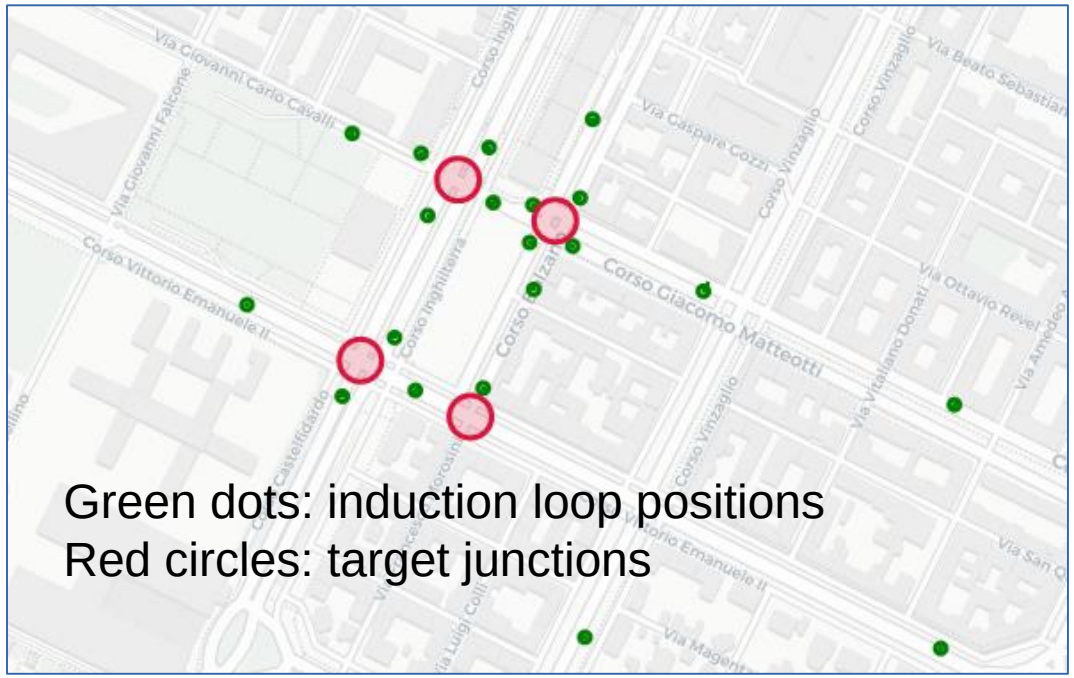
- 21 time series of induction loop sensor measurements at fixed known location, granularity of 300 seconds, overall time interval of 6 days

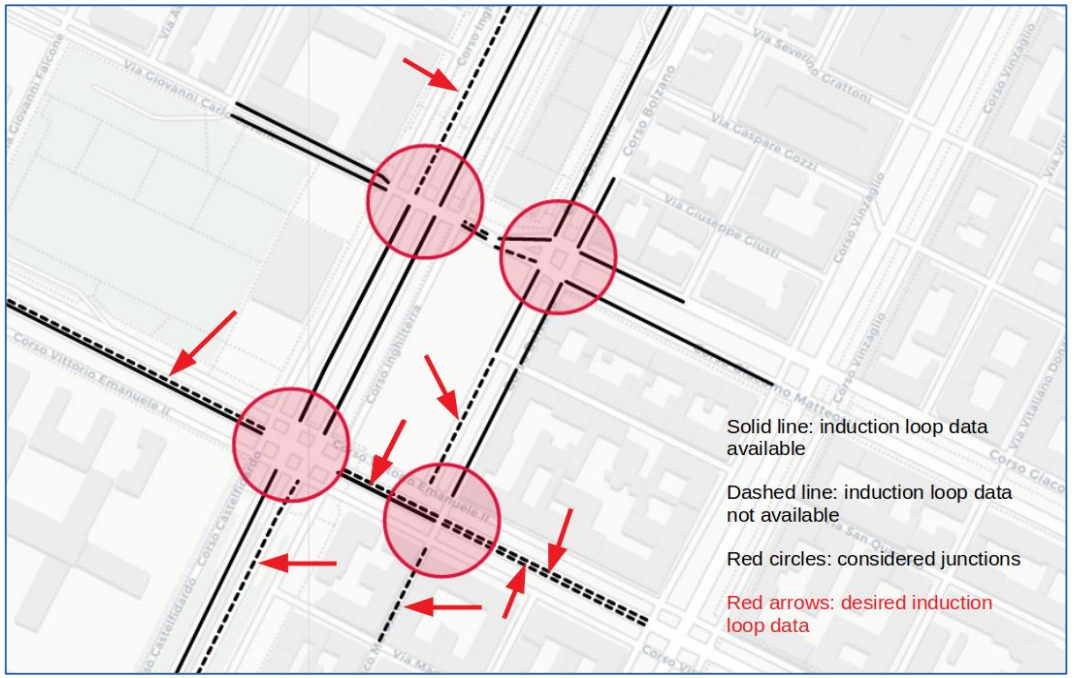



| | timestamp | timestamp_begin | timestamp_end | indl_id | edge_id | flow | speed |
|---|---|---|---|---|---|---|---|
| 1 | 2019-09-20 00:00:00 | 0 | 899 | 1320 | 190048065 | 65.926666666666666 | 0 |
| 2 | 2019-09-20 00:05:00 | 300 | 1199 | 1320 | 190048065 | 95.89333333333335 | 3 |
| 3 | 2019-09-20 00:10:00 | 600 | 1499 | 1320 | 190048065 | 98.89 | 3 |
| 4 | 2019-09-20 00:15:00 | 900 | 1799 | 1320 | 190048065 | 83.90666666666667 | 3 |
| 5 | 2019-09-20 00:20:00 | 1200 | 2099 | 1320 | 190048065 | 71.92 | 3 |
| 6 | 2019-09-20 00:25:00 | 1500 | 2399 | 1320 | 190048065 | 71.92 | 0 |
| 7 | 2019-09-20 00:30:00 | 1800 | 2699 | 1320 | 190048065 | 68.92333333333333 | 3 |
| 8 | 2019-09-20 00:35:00 | 2100 | 2999 | 1320 | 190048065 | 68.92333333333333 | 3 |
| 9 | 2019-09-20 00:40:00 | 2400 | 3299 | 1320 | 190048065 | 83.90666666666667 | 3 |
| 10 | 2019-09-20 00:45:00 | 2700 | 3599 | 1320 | 190048065 | 89.9 | 3 |
| 11 | 2019-09-20 00:50:00 | 3000 | 3899 | 1320 | 190048065 | 62.93000000000001 | 3 |
| 12 | 2019-09-20 00:55:00 | 3300 | 4199 | 1320 | 190048065 | 146.83666666666667 | 3 |
| 13 | 2019-09-20 01:00:00 | 3600 | 4499 | 1320 | 190048065 | 167.81333333333333 | 7 |
| 14 | 2019-09-20 01:05:00 | 3900 | 4799 | 1320 | 190048065 | 68.92333333333333 | 10 |
| 15 | 2019-09-20 01:10:00 | 4200 | 5099 | 1320 | 190048065 | 47.94666666666667 | 0 |
| 16 | 2019-09-20 01:15:00 | 4500 | 5399 | 1320 | 190048065 | 35.96 | 0 |
| 17 | 2019-09-20 01:20:00 | 4800 | 5699 | 1320 | 190048065 | 17.98 | 0 |
| 18 | 2019-09-20 01:25:00 | 5100 | 5999 | 1320 | 190048065 | 71.92 | 64 |
| 19 | 2019-09-20 01:30:00 | 5400 | 6299 | 1320 | 190048065 | 38.95666666666667 | 32 |
| 20 | 2019-09-20 01:35:00 | 5700 | 6599 | 1320 | 190048065 | 38.95666666666667 | 3 |
| 21 | 2019-09-20 01:40:00 | 6000 | 6899 | 1320 | 190048065 | 35.96 | 0 |
| 22 | 2019-09-20 01:45:00 | 6300 | 7199 | 1320 | 190048065 | 29.966666666666665 | 0 |
| 23 | 2019-09-20 01:50:00 | 6600 | 7499 | 1320 | 190048065 | 74.91666666666666 | 7 |
| 24 | 2019-09-20 01:55:00 | 6900 | 7799 | 1320 | 190048065 | 338.62333333333333 | 21 |
| 25 | 2019-09-20 02:00:00 | 7200 | 8099 | 1320 | 190048065 | 29.966666666666665 | 0 |
| 26 | 2019-09-20 02:05:00 | 7500 | 8399 | 1320 | 190048065 | 26.97 | 0 |
| 27 | 2019-09-20 02:10:00 | 7800 | 8699 | 1320 | 190048065 | 23.973333333333336 | 0 |
| 28 | 2019-09-20 02:15:00 | 8100 | 8999 | 1320 | 190048065 | 26.97 | 36 |
| 29 | 2019-09-20 02:20:00 | 8400 | 9299 | 1320 | 190048065 | 41.95333333333333 | 54 |
| 30 | 2019-09-20 02:25:00 | 8700 | 9599 | 1320 | 190048065 | 20.976666666666667 | 57 |
| 31 | 2019-09-20 02:30:00 | 9000 | 9899 | 1320 | 190048065 | 26.97 | 61 |
| 32 | 2019-09-20 02:35:00 | 9300 | 10199 | 1320 | 190048065 | 20.976666666666667 | 61 |

# Modeling of traffic flows: quality issues

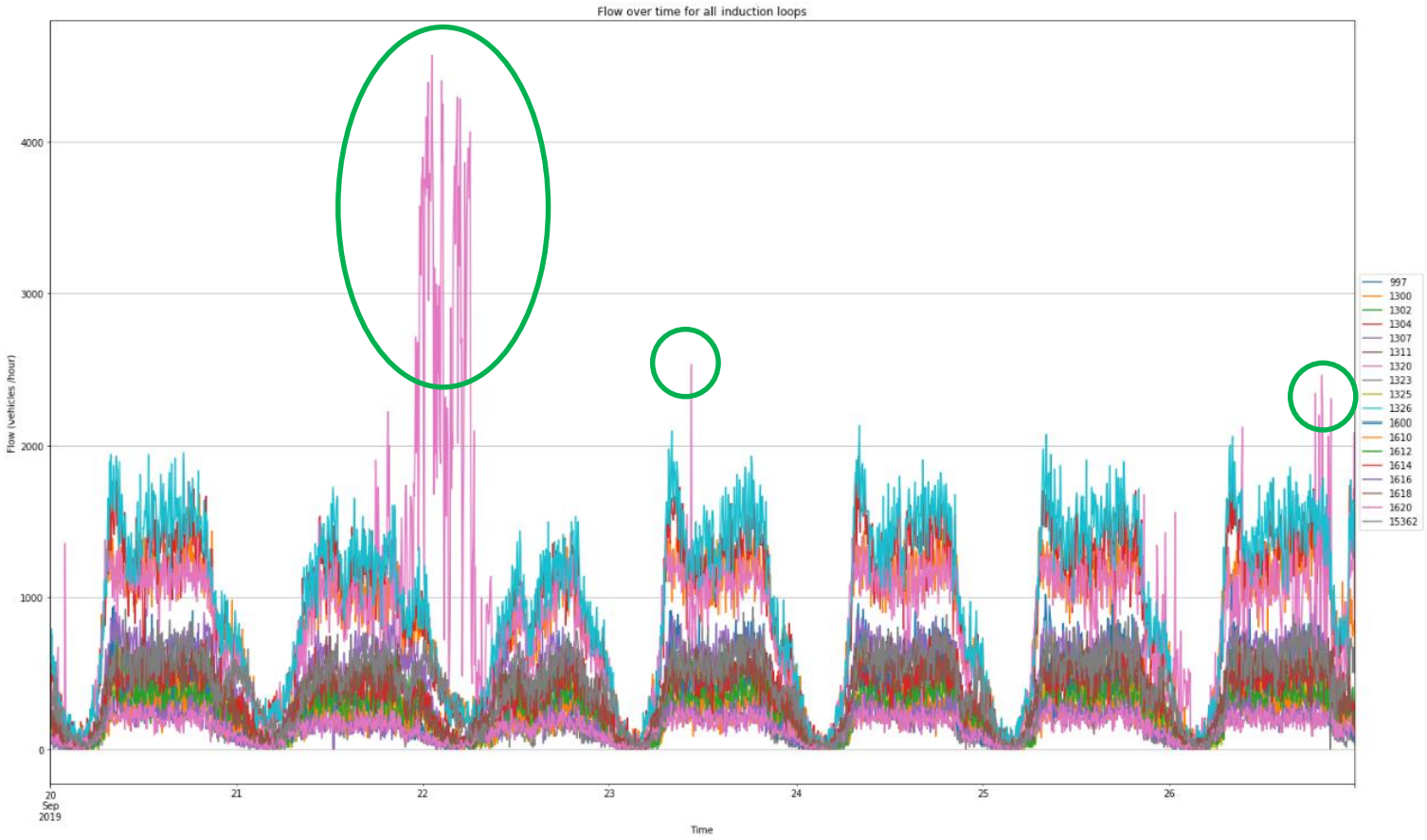
- Missing flow information for eight critical network edges



# Modeling of traffic flows: quality issues

- Noisy data points. E.g.: faulty induction loop ID 1320

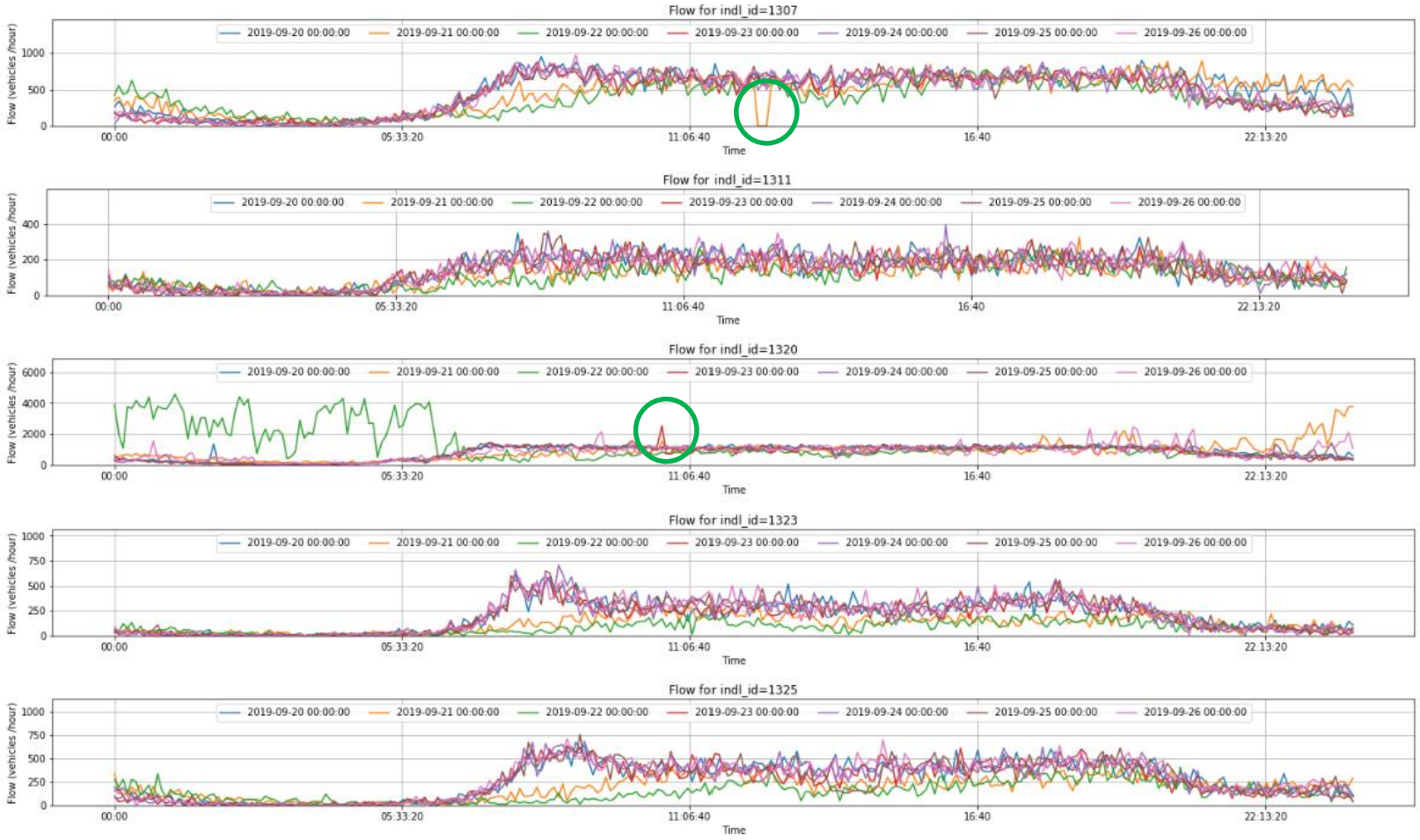


# Modeling of traffic flows: quality issues

- Noisy data points
- Example: outliers on induction loop IDs 1307, 1320

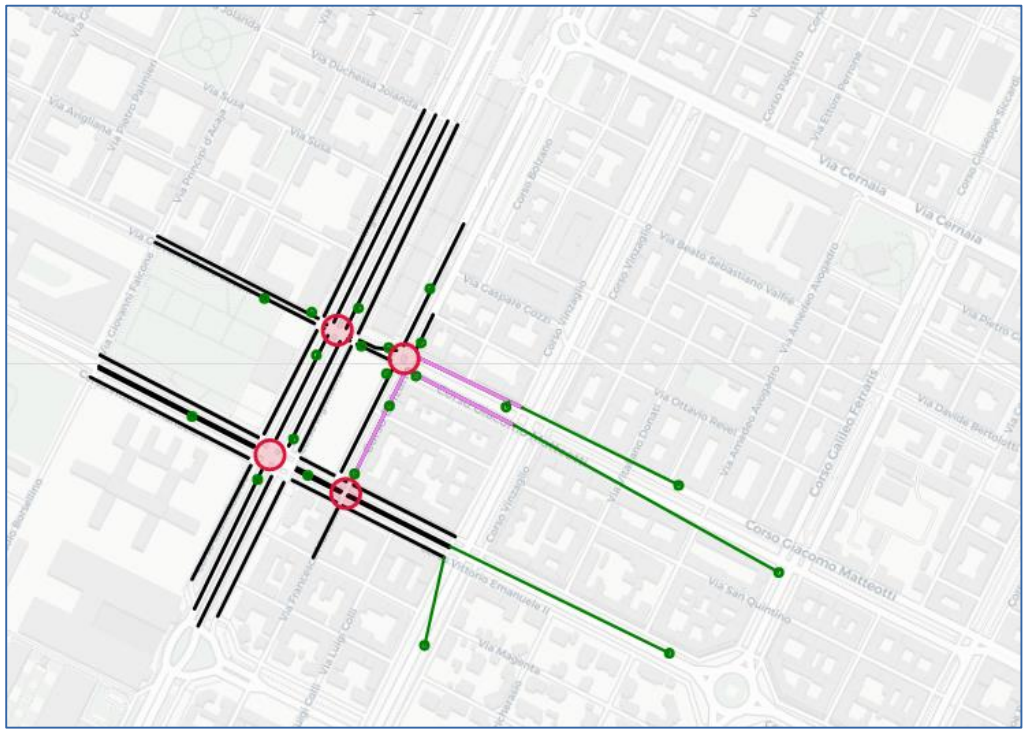
Notes:

- Sept 21, 22 is weekend
- Range on Y axis changes not fixed on plots



# Modeling of traffic flows: matching detectors-edges

- Automated matching of edge ID and induction loop ID and manual revision



**Black segments**: considered road network subset

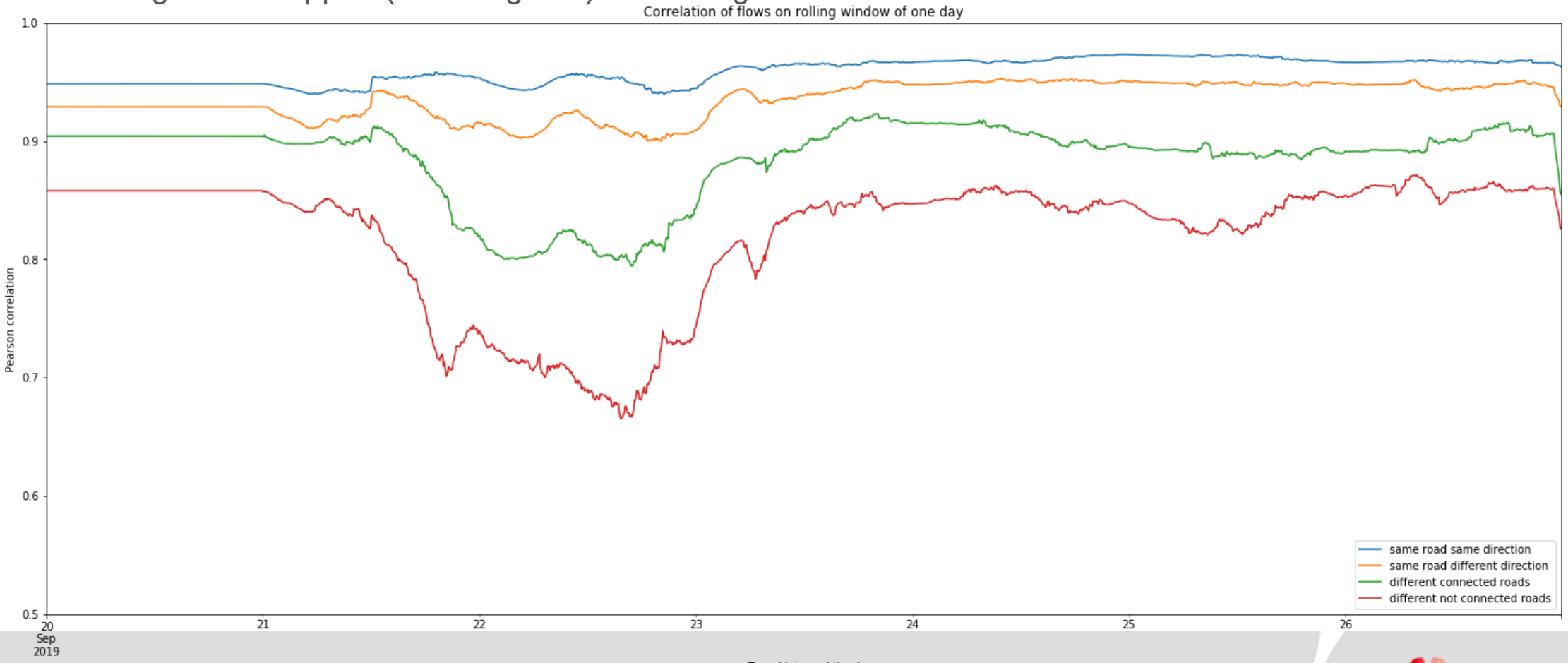
**Green circles:** induction loops

**Green segments:** shortest distance between induction loop and set of considered road edges

**Violet segments:** road network segments with more than one associated induction loop

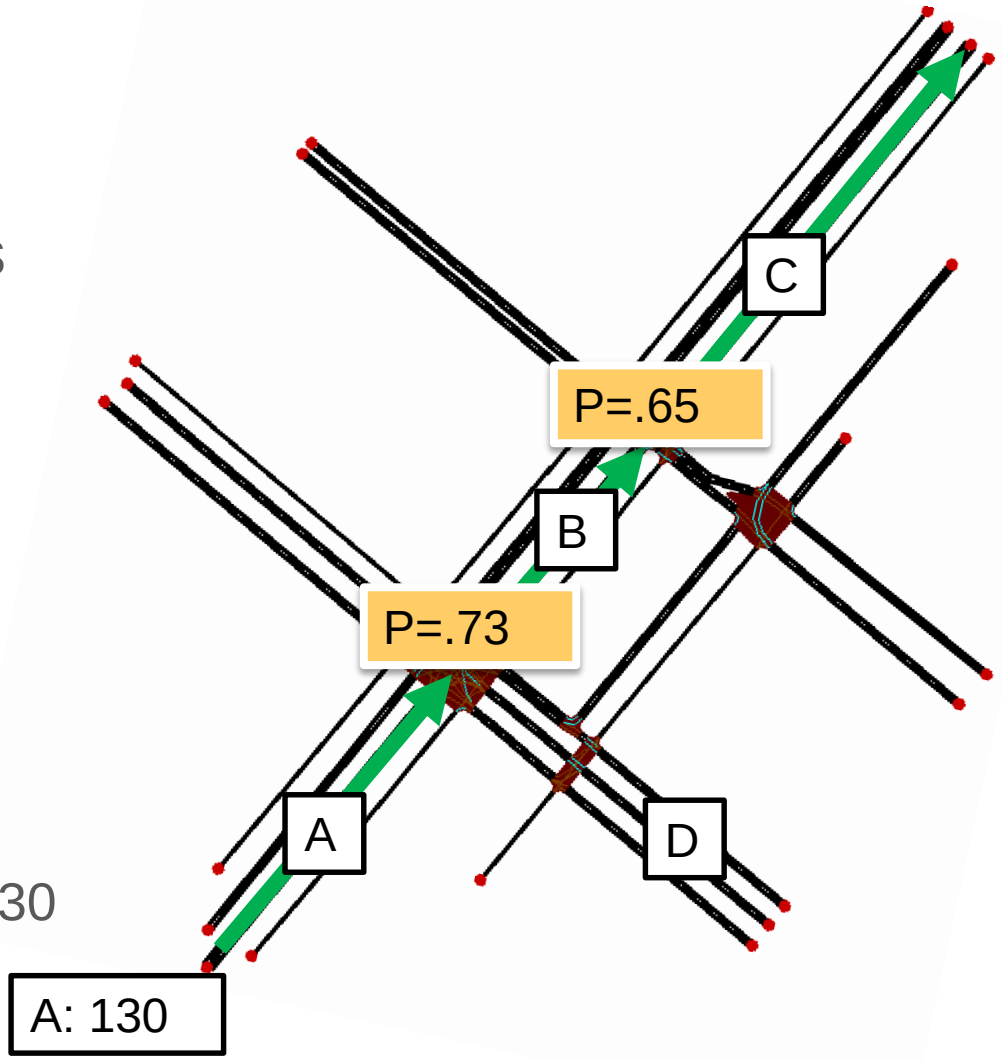
# Modeling of traffic flows: handling missing values

- **Level of flow correlation increases for intuitively more similar edges**: different and not connected roads < different but connected roads < same road but different direction < same road same direction
- Existing flows mapped (and weighted) to missing flows



# Modeling of traffic flows: Creating routes

- Vehicles modeled with routes
- A route is a trajectory with N cars injected during T seconds
- Given starting flow and edge-to-edge transition probabilities, possible to estimate route flow




Example:

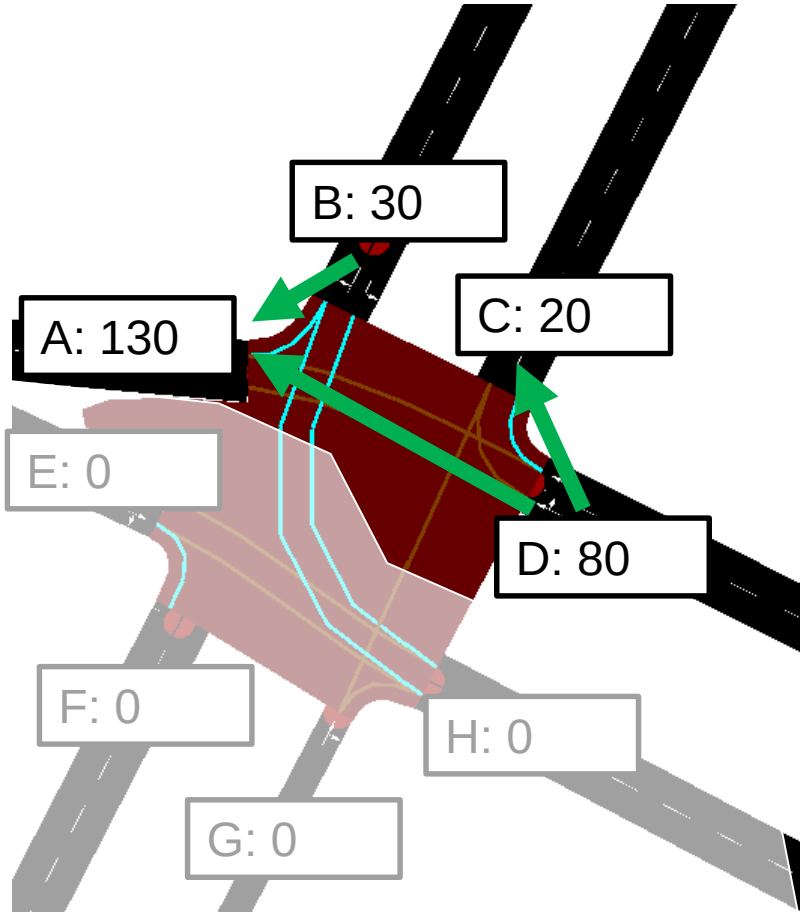
- route1 = ABC
- flow(route1) = flow(A)*P(AB)*P(BC) = 130 * 0.73 * 0.65 ~= 62

# Modeling of traffic flows: Estimating edge-to-edge transition probabilities

- Route flows estimates require edge-to-edge transition probabilities
- Frequency-based approach adopted

Example:

- P(DA) = “probability of vehicle in D to reach A”
- flow_outgoing(D) = flow(A)+flow(C) = 150
- P(DA) = flow(A)/flow_outgoing(D) = 130/150 = 0.86
- P(DC) = flow(C)/flow_outgoing(D) = 20/150 = 0.13



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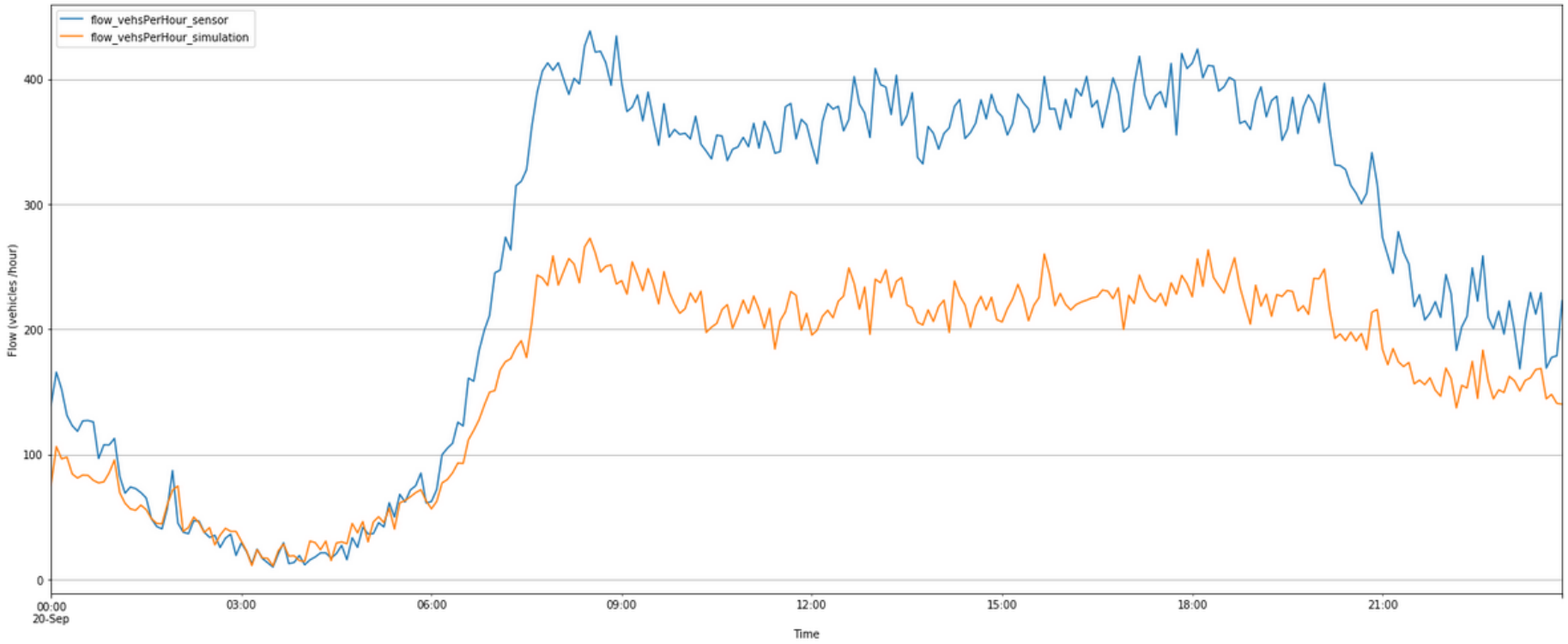
# QA: flows generation v1

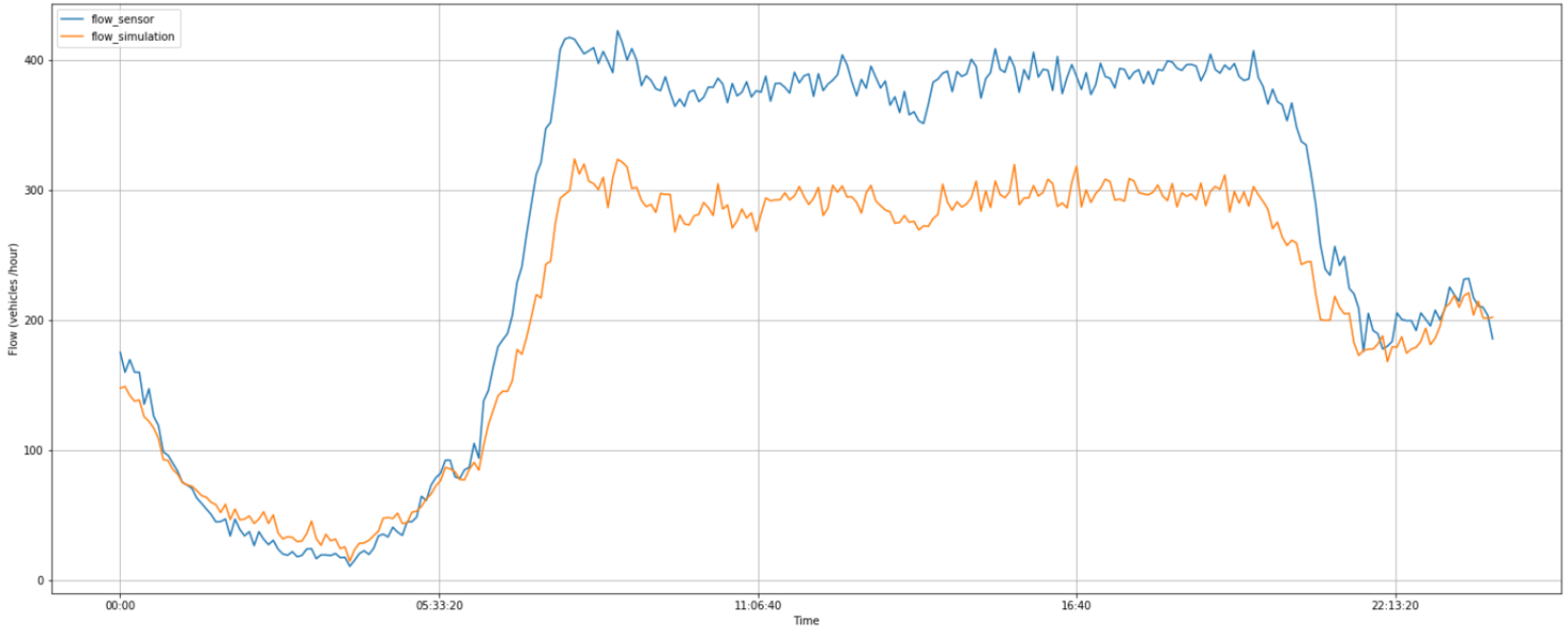
- Simulation flows underestimate flows reported by induction loops
- Possible cause: induction loop measurements overestimated?




Average flow per edge on network during test day “20-09-2019” over time

# QA: flows generation v2

- After feedback on flows, we improved our flow generation for a different day and calibration process improving the flow quality compared to v1
- The Pearson correlation score is 0.99 and the average absolute difference is 59.90




Average flow per edge on network during test day “20-12-2019” over time

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# Adaptive optimization of traffic flows: Experimental setup

- Traffic model generated for entire week during daytime (07:00-23:00)

- Quality metrics extracted from simulation:
  - Waiting time of vehicle during trip
  - CO2 emissions on road segment
  - […others possible: trip duration, …]

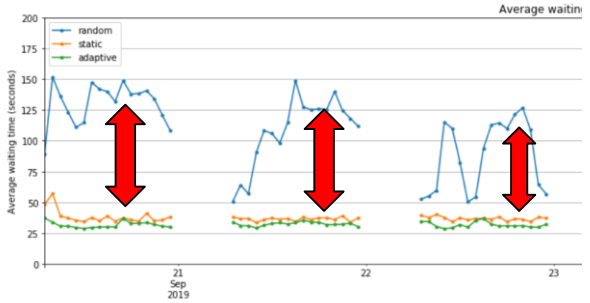
- Three strategies for green traffic light assignment evaluated:
  - **Static**: static plans for daytime as provided by 5T
  - **Random**: random plans consistent with green light duration constraints
  - **Adaptive**: Huawei adaptive system

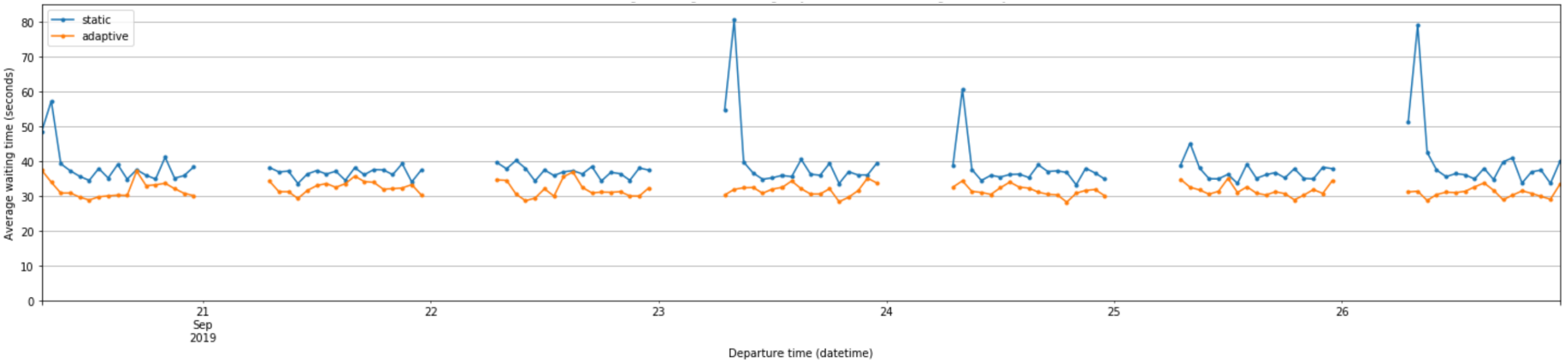
# Adaptive optimization of traffic flows

- Experimental setup
- **Experimental comparison of trips waiting time**
- Experimental comparison of CO2 emissions

# Adaptive optimization of traffic flows: Trips waiting time (September 2019)

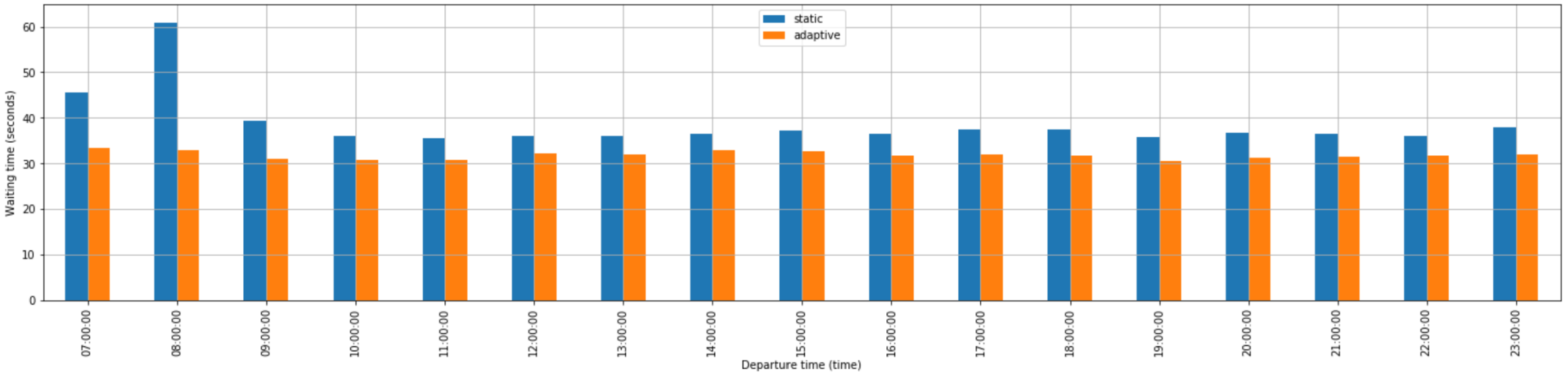
- Average waiting time of trips at 20 minuets granularity
- X axis: trip starting time; Y axis: waiting time of vehicle during trip
- **Adaptive** method consistently lower waiting time than **random** and **static** methods



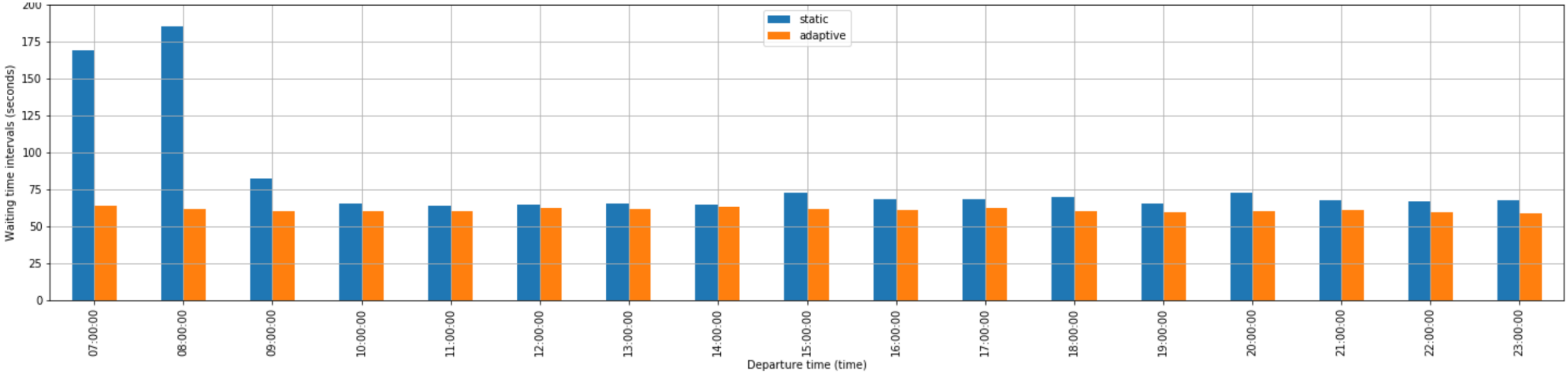
# Adaptive optimization of September traffic flows: Trips waiting time

- Average waiting time of trips starting at hour granularity during daytime
- **Adaptive** model leads to 18% lower waiting times than **static** on average



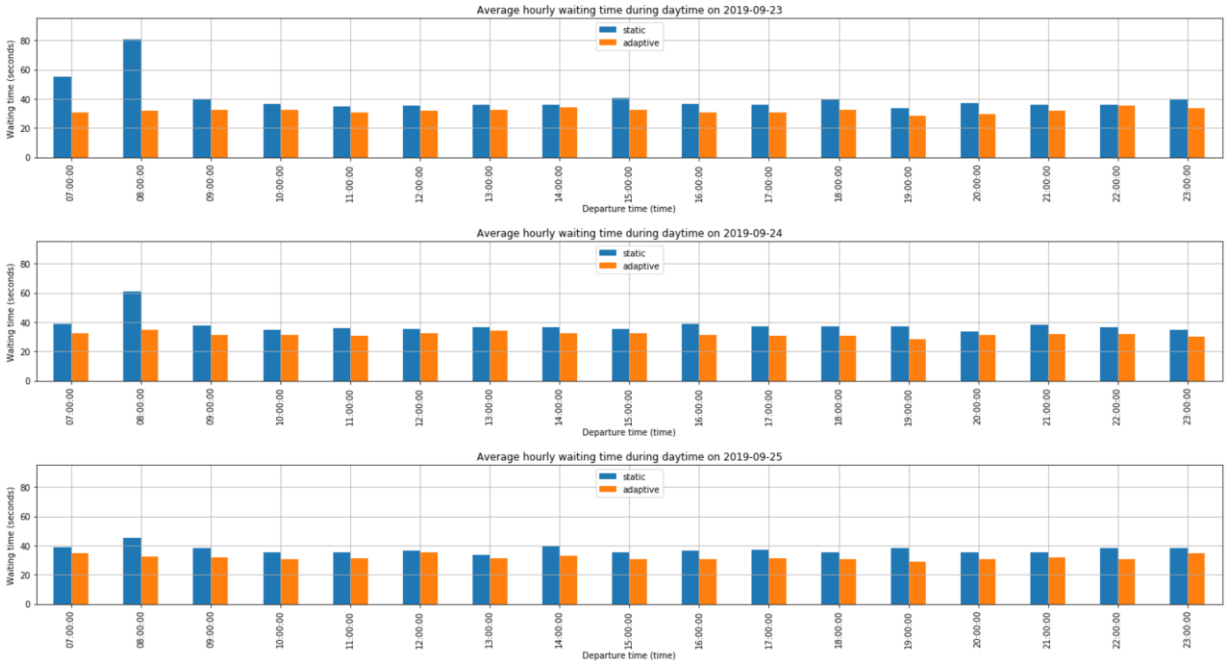
# Adaptive optimization of September traffic flows: Trips waiting time standard deviation

- Distance between average and 95% of trip waiting times
- **Static** and **random** strategies consistently wider intervals than **adaptive**
- **Adaptive** model leads to more stable behavior also during weekends



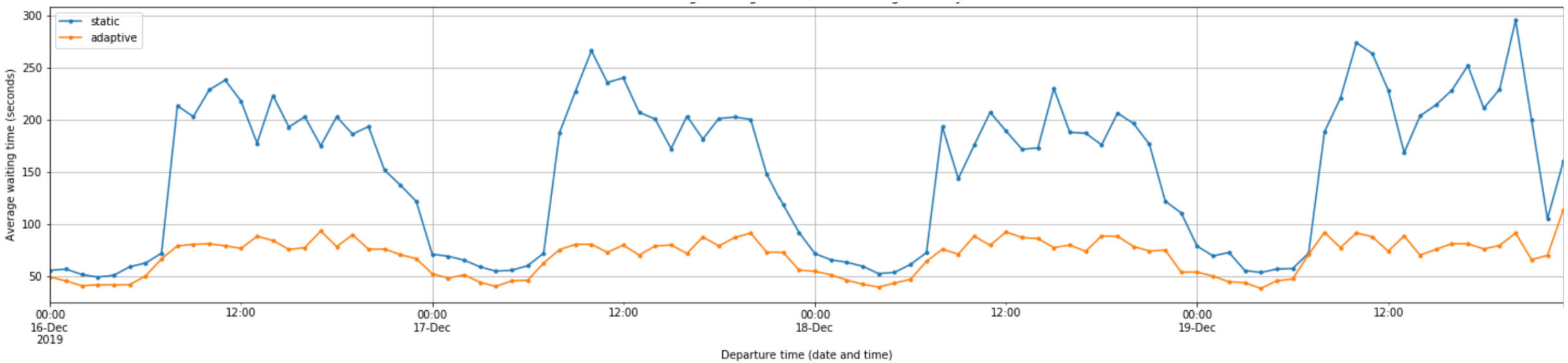
# Adaptive optimization of September traffic flows: Trips waiting time

- Average trip waiting time: breakdown per day
- Average waiting time drops on average by 18% from **static** to **adaptive** strategy

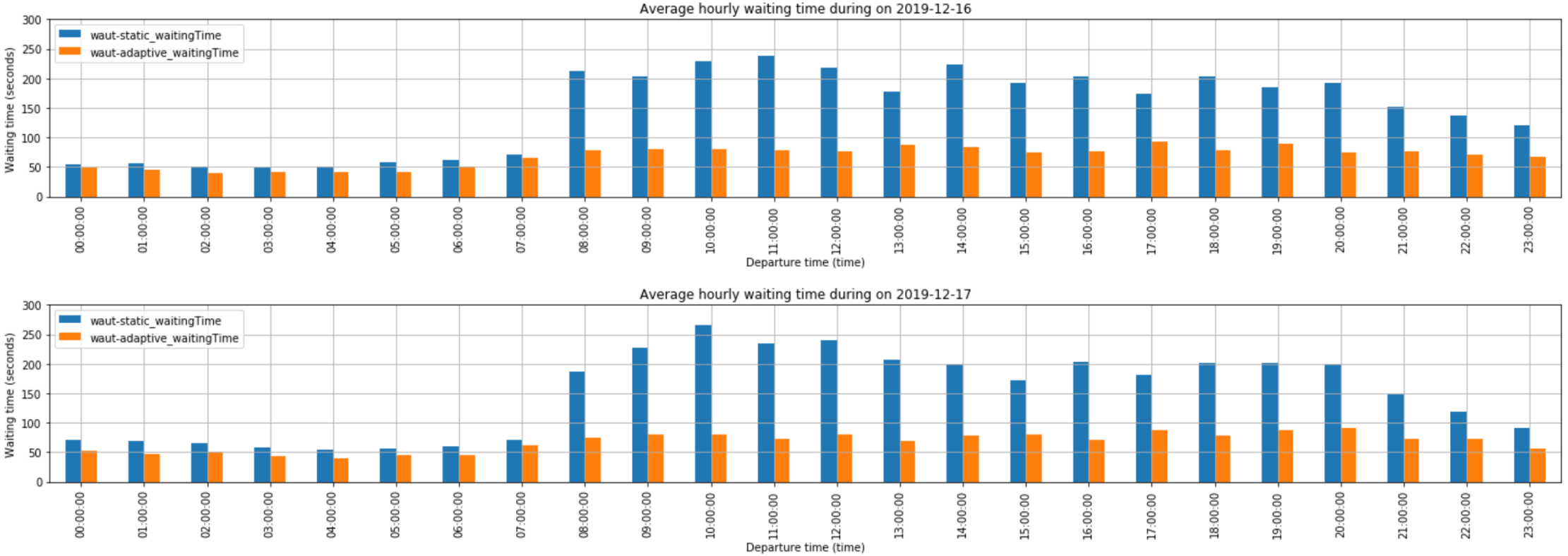
# Adaptive optimization of traffic flows: Trips waiting time (December 2019)

- Average waiting time of trips at 60 minuets granularity
- X axis: trip starting time; Y axis: waiting time of vehicle during trip
- **Adaptive** method consistently lower waiting time than **adaptive static** methods



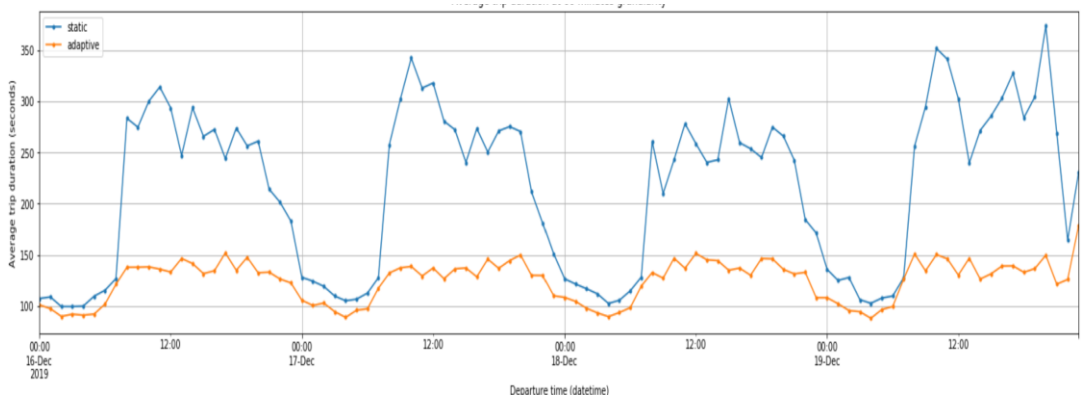
# Adaptive optimization of December traffic flows: Trips waiting time

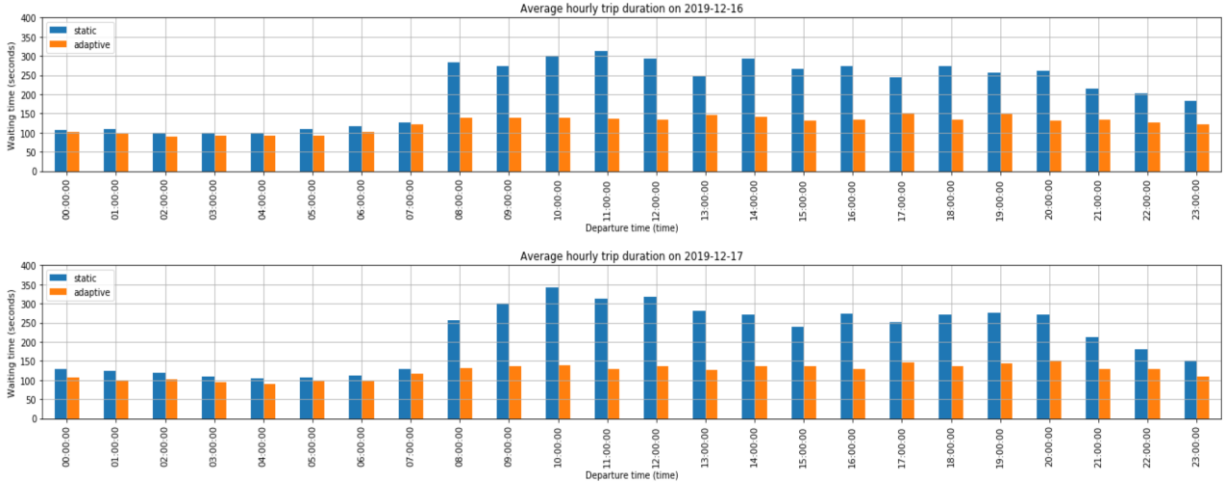
- Average waiting time of trips starting at hour granularity during daytime
- **Adaptive** model leads to 55% lower waiting times than adaptive **static** on average (from 165 seconds to 73 seconds in average)



# Adaptive optimization of December traffic flows: Average Trip Duration

- measured average trip duration drops from 232 to 131 seconds, with an average gain of 43% with adaptive algorithm compared with static adaptive
- peeks of ~60% gain with ~350 seconds average duration against ~140 seconds of the adaptive system



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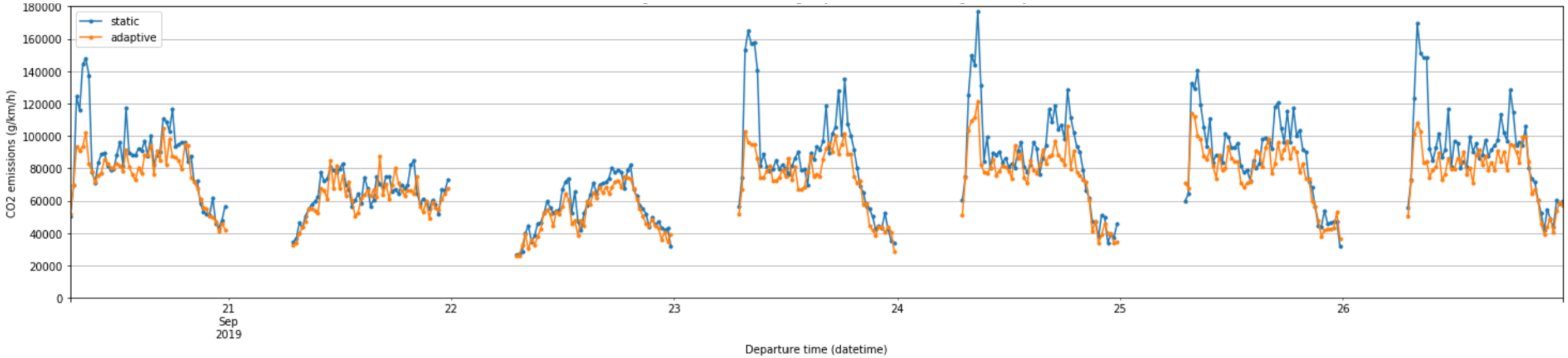
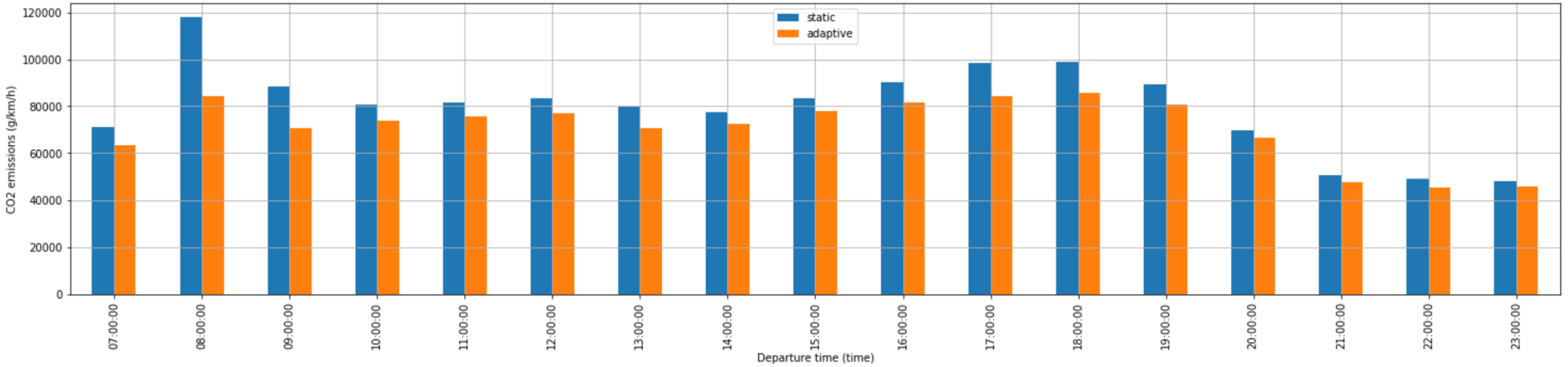
# Adaptive optimization of traffic flows: Trips CO2 emissions

- Average CO2 emissions of trips at 20 minuets granularity per road segment
- X axis: trip starting time
- Y axis: CO2 emissions (g/km/h)



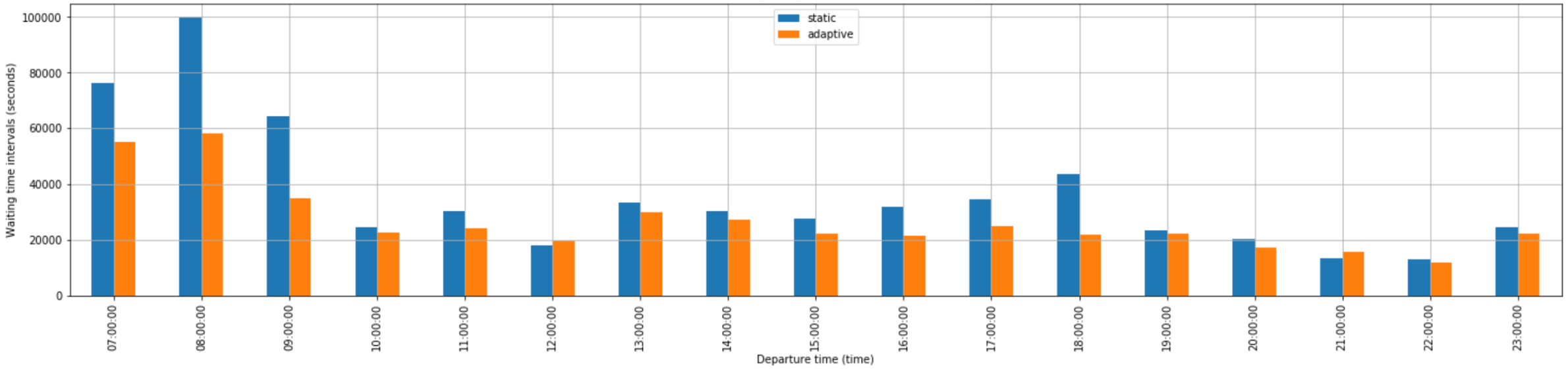
# Adaptive optimization of traffic flows: Trips CO2 emissions

- Average CO2 emissions per edge starting at hour granularity during daytime
- **Adaptive** model leads to consistently lower CO2 emissions
- On average, reduction of CO2 emissions by 11% from **static** to **adaptive**



# Adaptive optimization of traffic flows: Trips CO2 emissions

- Distance between average and 95% of edge CO2 emissions
- **Static** strategy has wider interval than **adaptive** on 25% daytime hours



# Agenda

1. From raw data to simulation model
   a. Modeling of road network
   b. Modeling of traffic light programs
   c. Modeling of traffic flows
   d. Quality assessment of simulation model

2. Adaptive optimization of traffic flows
   a. Experimental setup
   b. Experimental comparison of trips waiting time (9/19 and 12/19 flows)
   c. Experimental comparison of CO2 emissions (9/19 flows)

3. **Concluding remarks**

# Concluding remarks

- During the cooperation and experimental phase, we tried to be as fair as possible in the evaluation, and we were honestly pleased to see how the work done was actually corresponding to our expectation, showing performance improvements compared to baseline.
- SUMO is not fit for realistic traffic modeling, largest effort was done on generating and calibrating the traffic flow, which kept anyway a relevant error compared to the original data
- Our experiments show considerable improvement (50+% gain in waiting time and trip duration), also considering the adaptive plans shared with us at 30 minutes granularity.
- We believe that detectors error may overestimate traffic flow, and reproducing it in the simulator may have overestimated traffic generating abnormal performance gap. Nevertheless, we shared the results as they are and with the related caveats related to the uncertainty of SUMO quality

# Thank You!