Predicting Time-to-Green for Fully-actuated Signal Control Systems with Deep Learning Models

Alexander Genser

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Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

MOTIVATION

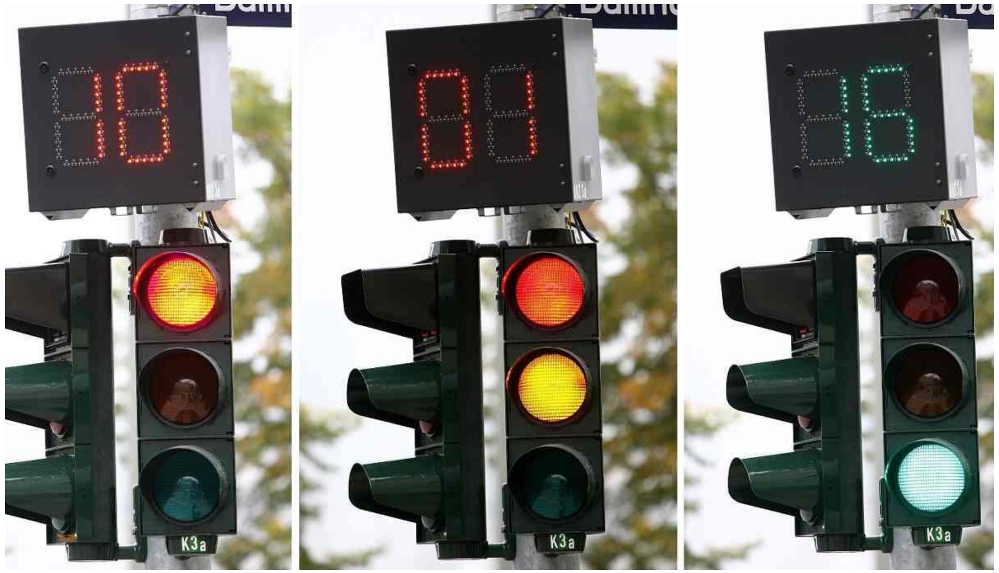
Motivation – Time-2-Green countdowns

- Red and green phases dependent on traffic demand and public transportation

Oft unregelmässig lange Rotphasen

In der Schweiz hatte es 2015 einen Vorstoss auf Bundesebene für «Countdown-Ampeln» landesweit gegeben. Die Forderung der Berner SP-Nationalrätin Margret Kiener Nellen wurde vom Bundesrat abgewiesen. Die Landesregierung begründete ihre Haltung unter anderem damit, dass sich Rot- und Grünphasen von Ampeln oft nach dem Verkehrsaufkommen sowie dem öffentlichen Nahverkehr richten und somit die Rotphasen unterschiedlich lang sein würden.

Source: nau.ch, 2020.

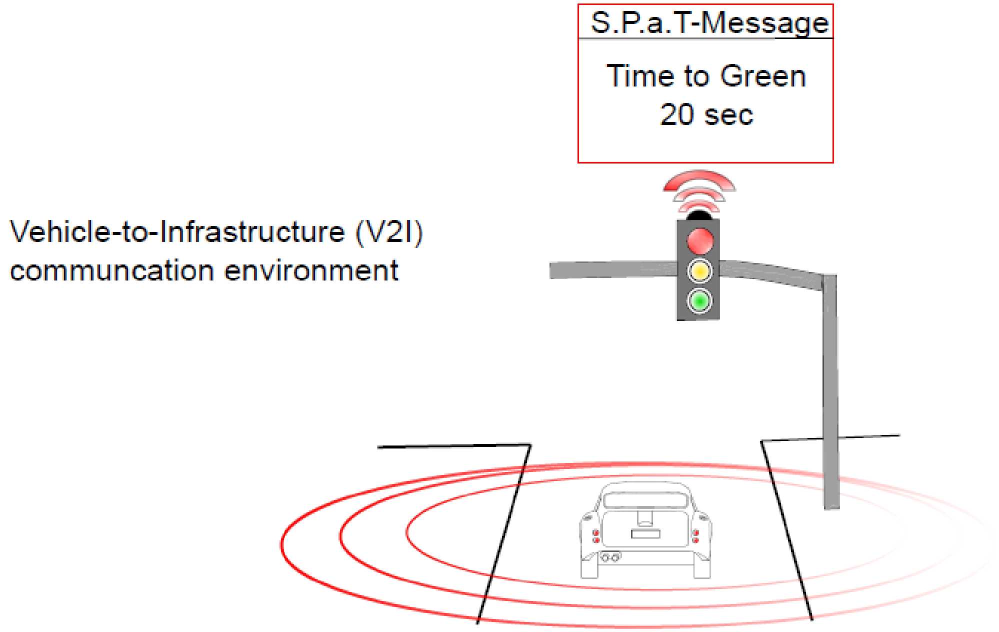


Source: rp-online.de, 2019.

Motivation – Speed advisory systems

- Enhancement of Signal Phase and Timing (SPaT) messages
  - Beneficial for **speed advisory systems**
  - Efficient and environmental friendly motion planning (**homogeneous** speed profiles)

- Requirement - Robust prediction of Time to Green (T2G)



PROBLEM DEFINITION

State-of-the-art signal control systems

- Types of signal control systems
  - Non-actuated
  - Semi-actuated
  - Fully-actuated

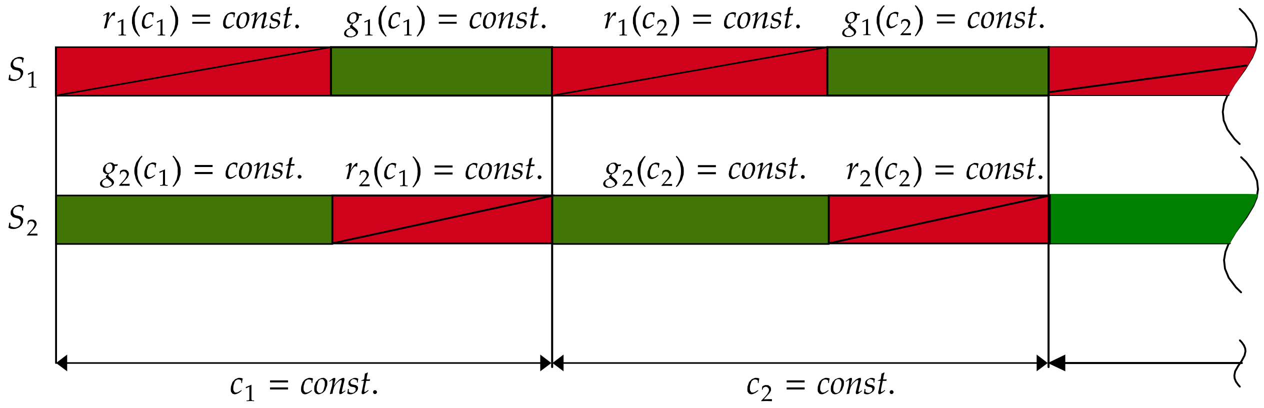
- None to fully flexible systems

  for control according to traffic dynamics

Non-actuated signal control systems

- Non-actuated signal control system
  - Green time $g_i(c_i)$, red time $r_i(c_i)$, cycle-time c_i of signal i are **constant**
  - **No reaction** to traffic dynamics / public transportation

System	$r_i(c_i)$	$g_i(c_i)$	c_i
None	const.	const.	const.
Semi	nonconst.	nonconst.	const.
Fully	nonconst.	nonconst.	nonconst.

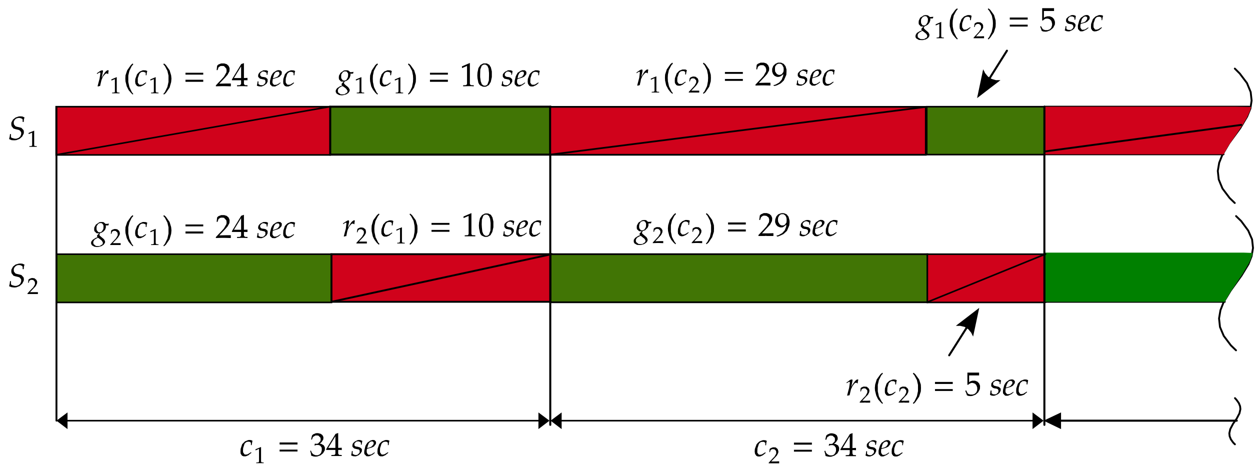


Semi-actuated signal control systems

- Semi-actuated signal control system
  - Green time $g_i(c_i)$, red time $r_i(c_i)$ of signal i are **non-constant**
  - Extension of green-time (e.g., priority for public transportation)

- T2G prediction with constraint that **cycle durations are fixed**

System	$r_i(c_i)$	$g_i(c_i)$	c_i
None	const.	const.	const.
Semi	nonconst.	nonconst.	const.
Fully	nonconst.	nonconst.	nonconst.

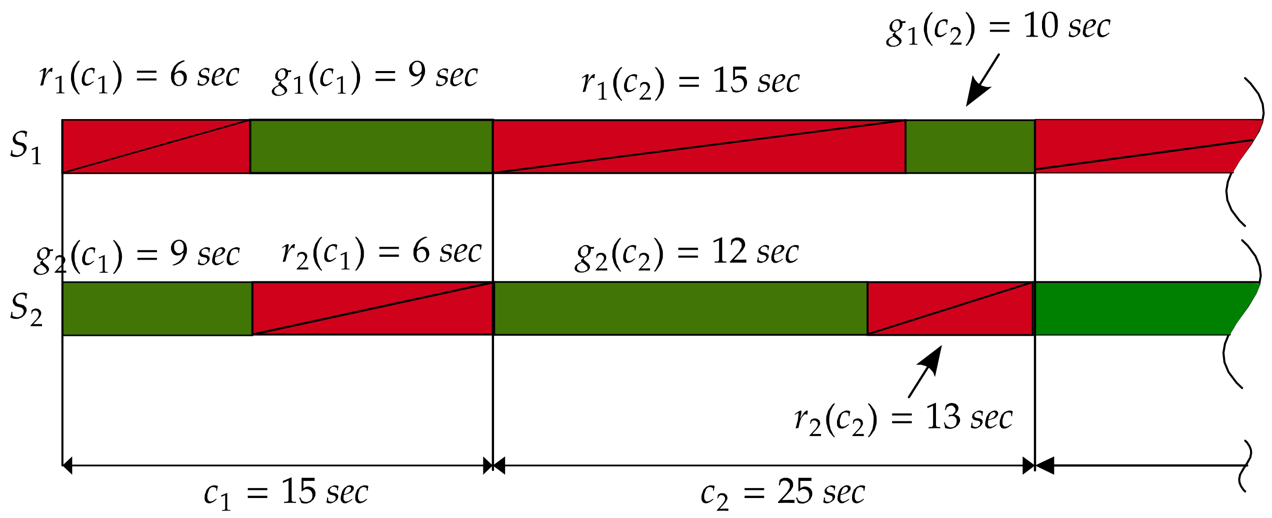


Fully-actuated signal control systems

- Full-actuated signal control system
  - Green time $g_i(c_i)$, red time $r_i(c_i)$, cycle-time c_i of signal i are **non-constant**
  - No variables have a fixed time quantity

- T2G prediction without pre-defined constraints

System	$r_i(c_i)$	$g_i(c_i)$	c_i
None	const.	const.	const.
Semi	nonconst.	nonconst.	const.
Fully	nonconst.	nonconst.	nonconst.



Problem definition

- **Continuous development** of traffic signal control systems
  - Flexible systems through sensor technology (detectors, Bluetooth, thermal cameras, etc.)
  - Optimization methods (VS-PLUS, Self-control, etc.)
- Cycle times, green or red times **not constant**
- Prediction model must capture **the target's variance**

Pilot study in the city of Lucerne: Self-control light-signal systems

16.12.2020

By: SVT, City of Lucerne

Rising requirements for mobility and the environment demand new ideas, especially in regard to efficency and sustainability.

Traffic light (CC0 1.0 / S. Sakharovskiy via Unsplash)

The city of Lucerne has analyzed the improvement of current traffic flow using existing infrastructure. In a pilot study a brand new approach for light-signal systems has been tested. Read on

IVT, ETH, 2020.

Problem definition

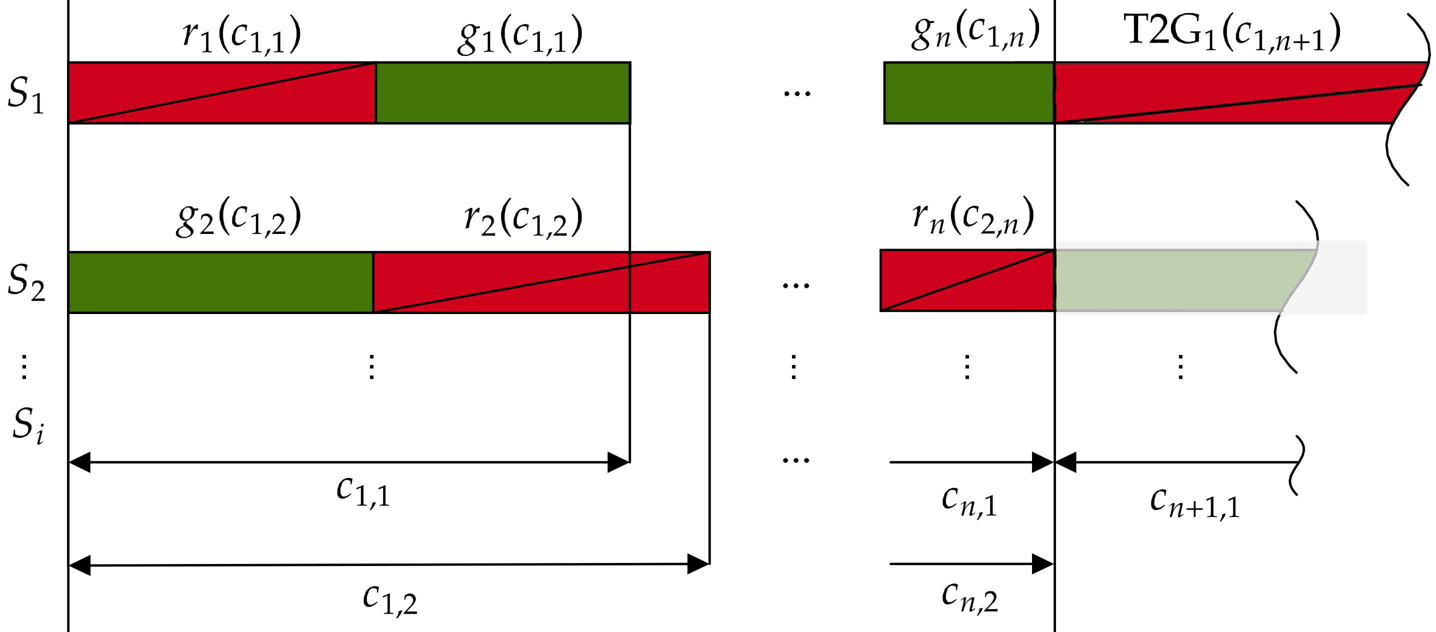
- Prediction of T2G with $f(X)$, where X contains all concatenated inputs

<u>Input data</u>

$$\mathbb{C} = \{c_{1,i},\ c_{2,i},\ \dots\ c_{n,i}\} \quad \forall i$$
$$\mathcal{G} = \{g_1(c_{1,1}),\ g_1(c_{1,2}),\ \dots\ g_i(c_{i,n})\} \quad \forall i, n$$
$$\mathcal{R} = \{r_1(c_{1,1}),\ r_1(c_{1,2}),\ \dots\ r_i(c_{i,n})\} \quad \forall i, n$$

<u>Prediction</u>

$$\mathrm{T2G}_i(c_{i,n+1}) = f(X)$$



Problem definition

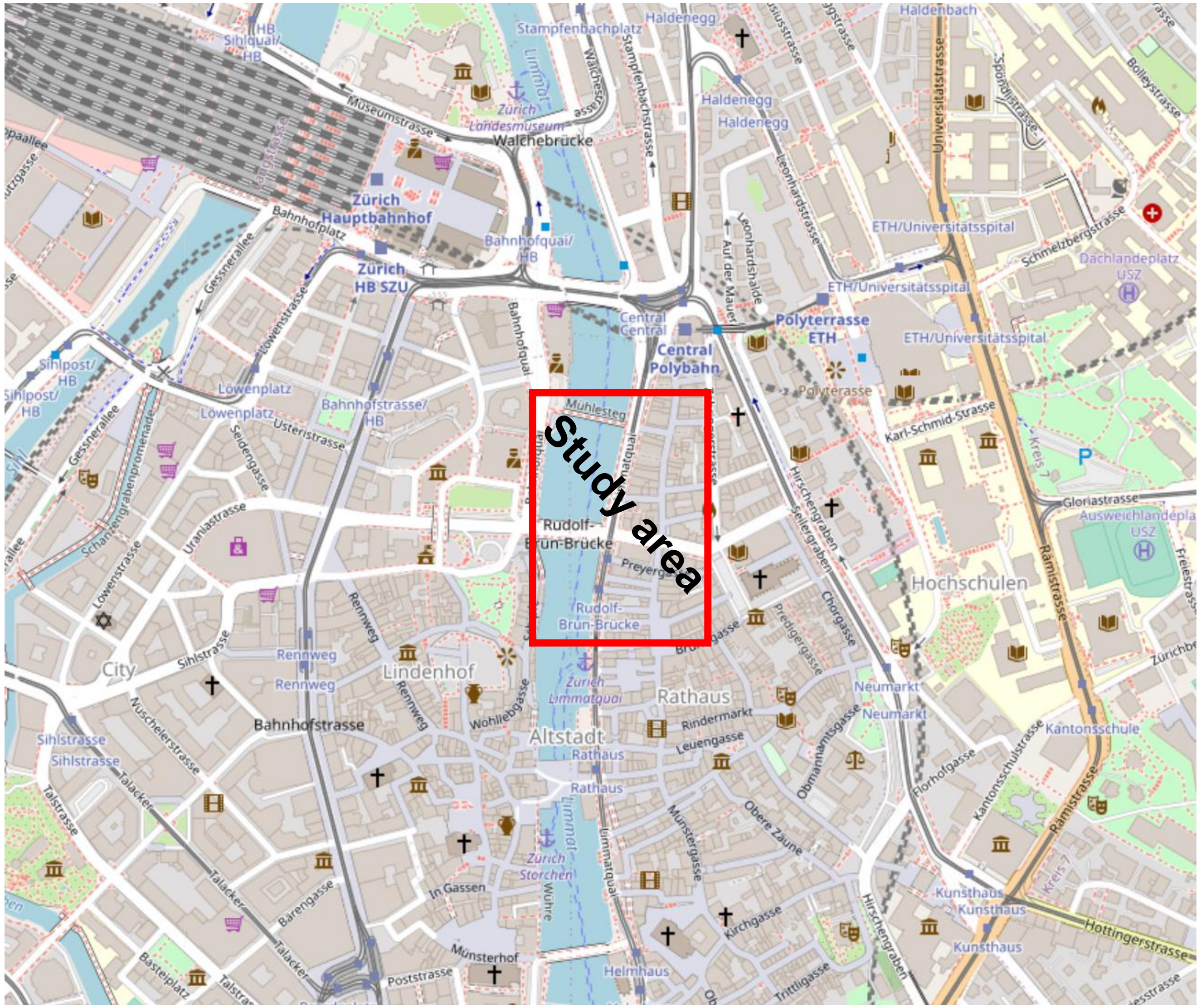
- Previous research is based on
  - Vehicle trajectories (demanding data requirements)
  - Considering **only traffic signal data**
  - **Fixed** cycle times (semi-actuated)
  - **No consideration of public transportation** dynamics

Prediction of Time-2-Green (T2G) for **fully-actuated signal control system** by utilizing **detector and traffic signal data.**

STUDY AREA AND DATA SET

Study area

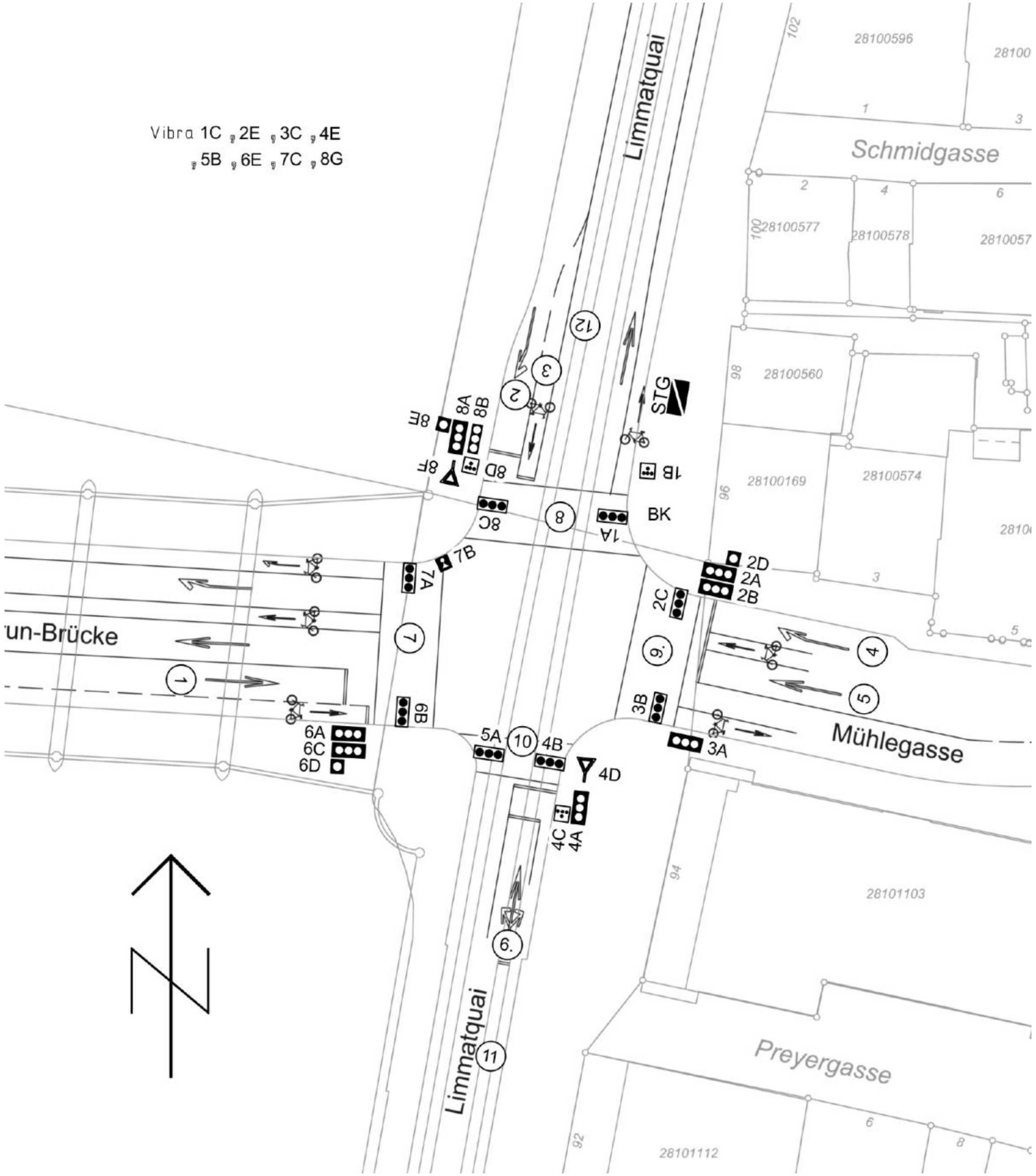
- Intersection in the center of Zurich, CH
- Traffic modes: Individual, public transportation, pedestrians and cyclists
- **Fully-actuated** signal control system



Source: OpenStreetMap (2022)

Study area

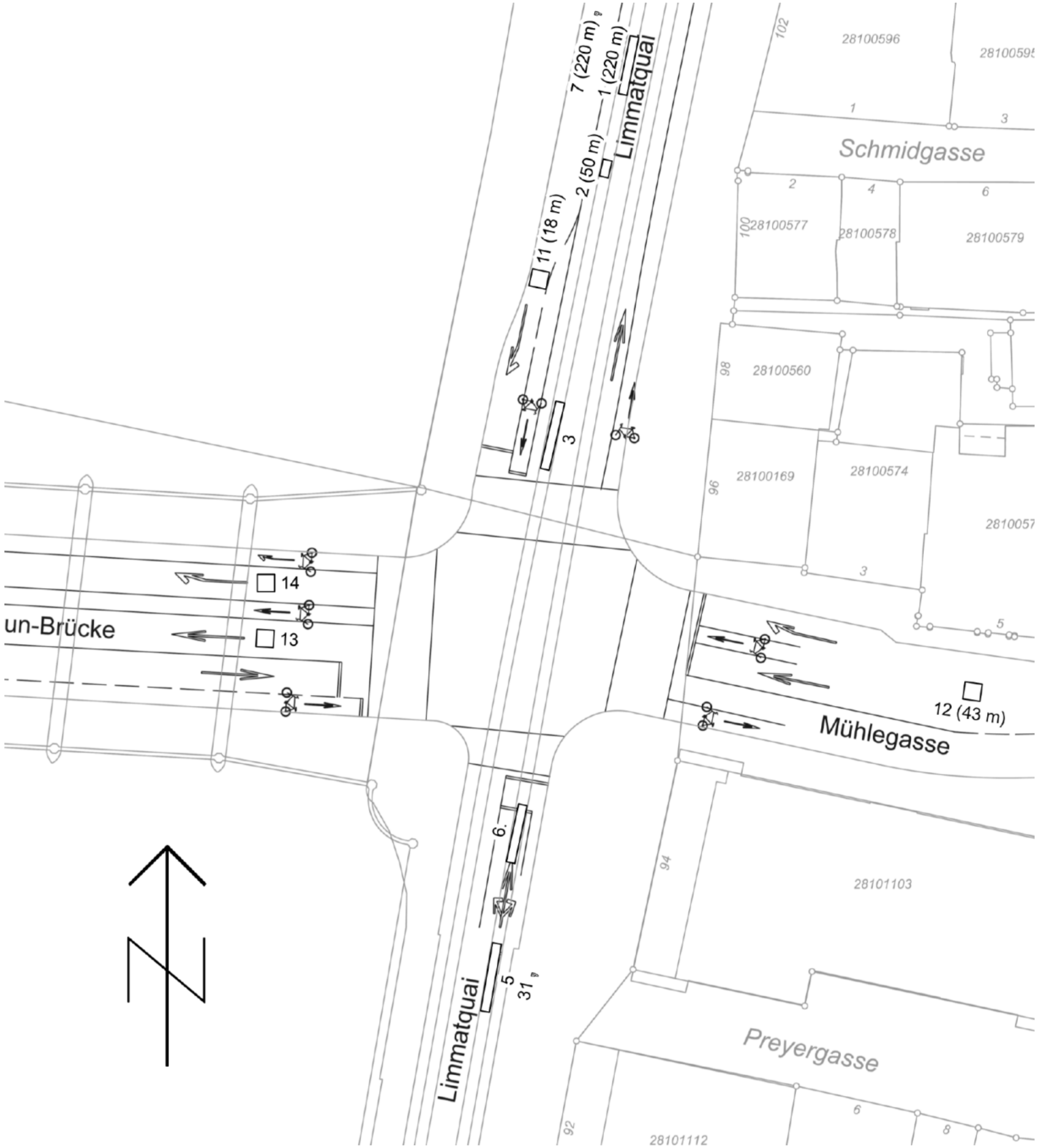
- All traffic flows controlled by traffic control system
- 12 traffic lights employed (3 signals are for tram line)
- Pedestrian flows are co-regulated with individual transportation



Source: Dienstabteilung Verkehr Zurich (2022)

Study area

- 12 inductive loop detectors installed
- Every arriving vehicle is detected
- Dedicated loop detectors for trams
- No separate detection of bicycle traffic

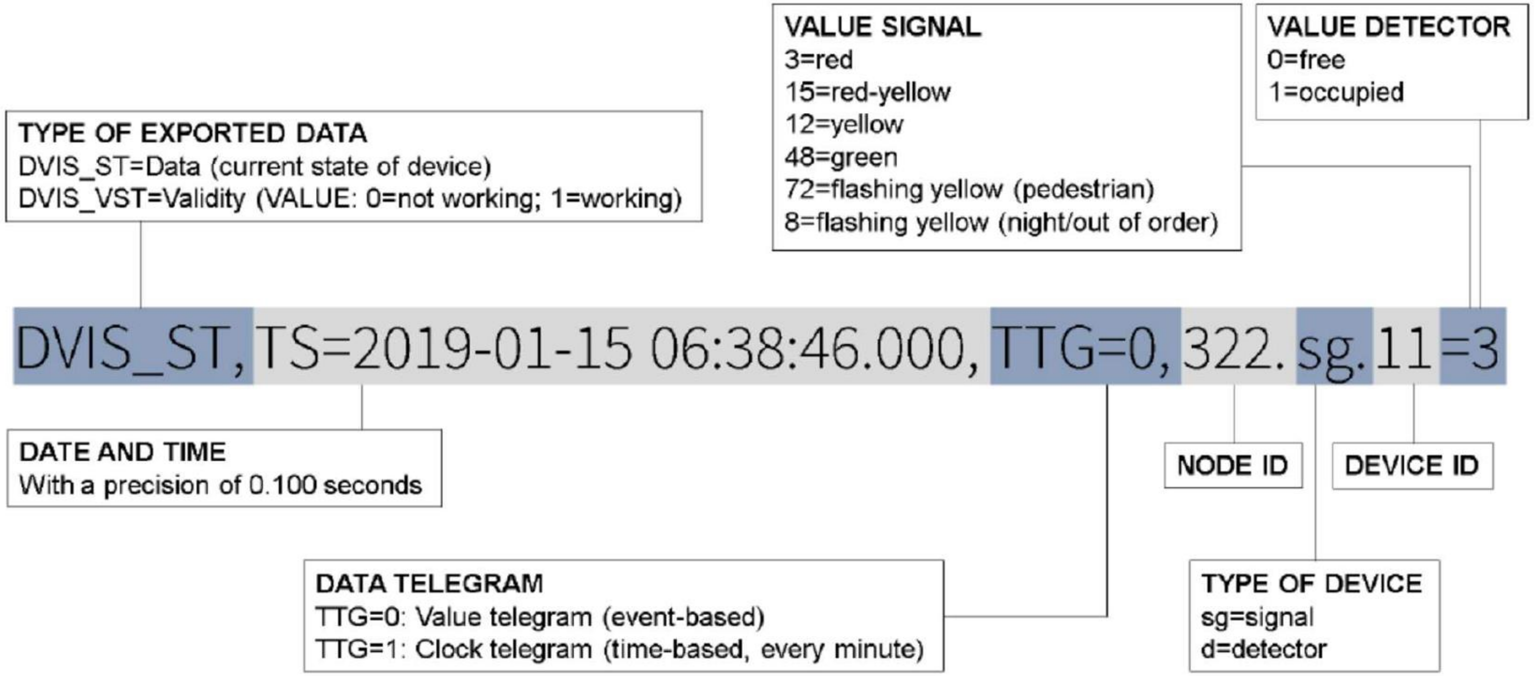


Source: Dienstabteilung Verkehr Zurich (2022)

Data format and processing

- Data processing of event-based telegrams including detectors and traffic signals

- Transformation into a data set as input for machine learning
  - Time series for each device
  - Data resolution = 1 sec.



Source: Dienstabteilung Verkehr Zurich (2022)

Feature Engineering

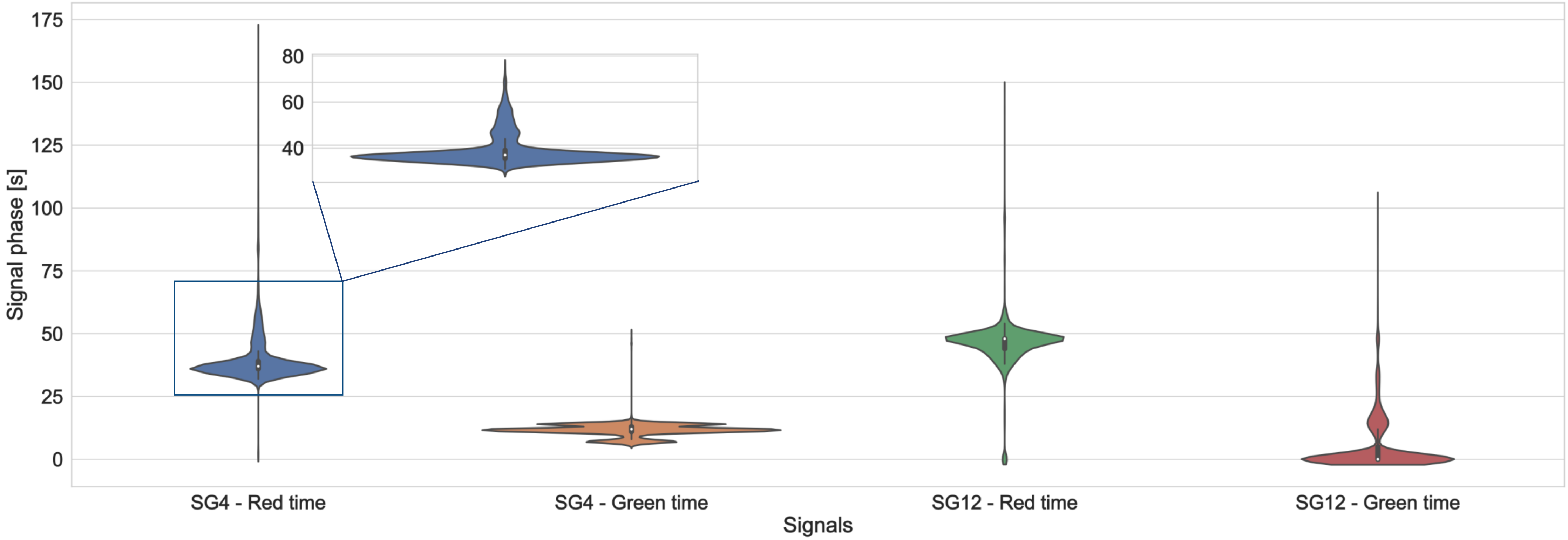
- Aggregated data set (cycles) of traffic signals and detectors
- Two weeks of data (Monday – Friday, 7:00 and 20:00)

- Computation of feature set (R=red time, G=green time):

Feature	Variable
Red and green time [s]	$r_i(c_{n,i})$, $g_i(c_{n,i})$
Traffic flow at red and green time [veh/phase]	$q_{i,\mathrm{R}}(\cdot)$, $q_{i,\mathrm{G}}(\cdot)$
Detector occupancy for red and green time [detections/phase]	$o_{i,\mathrm{R}}(\cdot)$, $o_{i,\mathrm{G}}(\cdot)$
Congestion indicator [-]	$u_i(\cdot)$
Queue indicator [-]	$v_i(\cdot)$

Feature Engineering

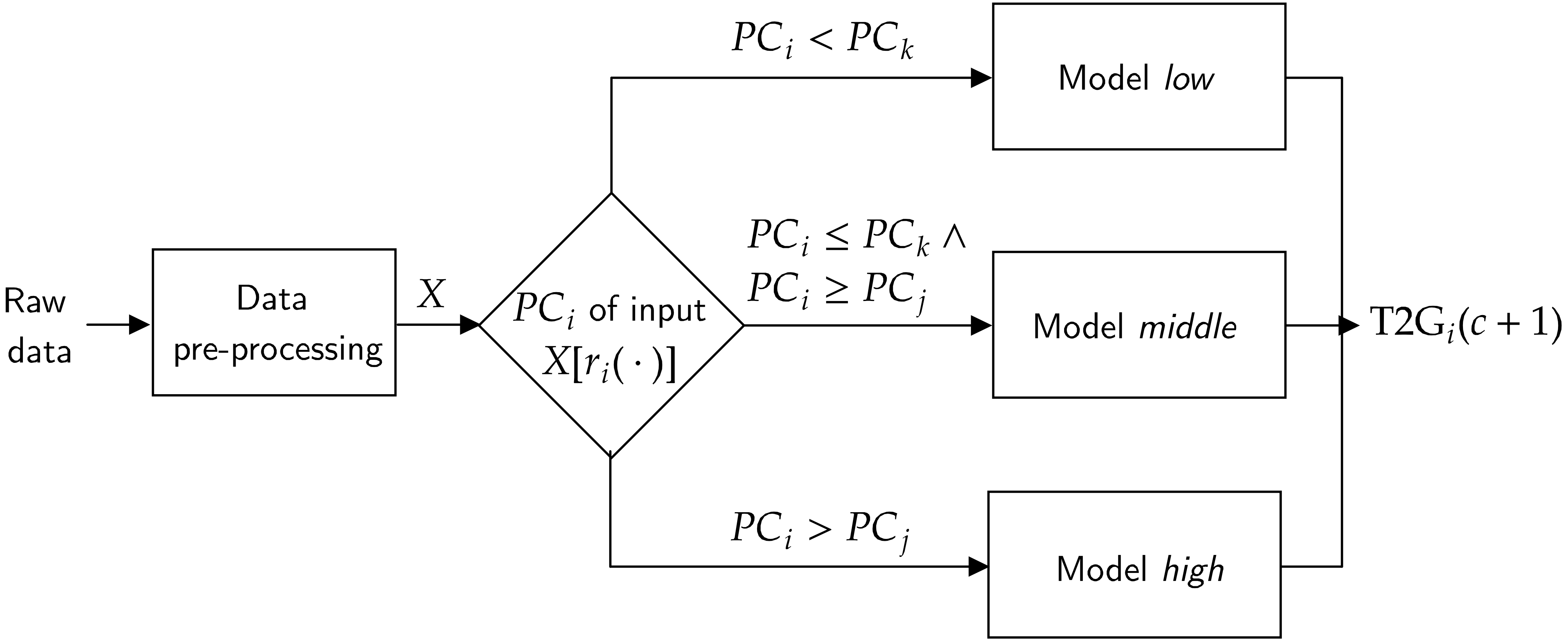
- Long tailed features due to extreme events (high traffic demand, public transportation priority, etc.)
- Other features show similar characteristics



METHODOLOGY T2G-PREDICTION

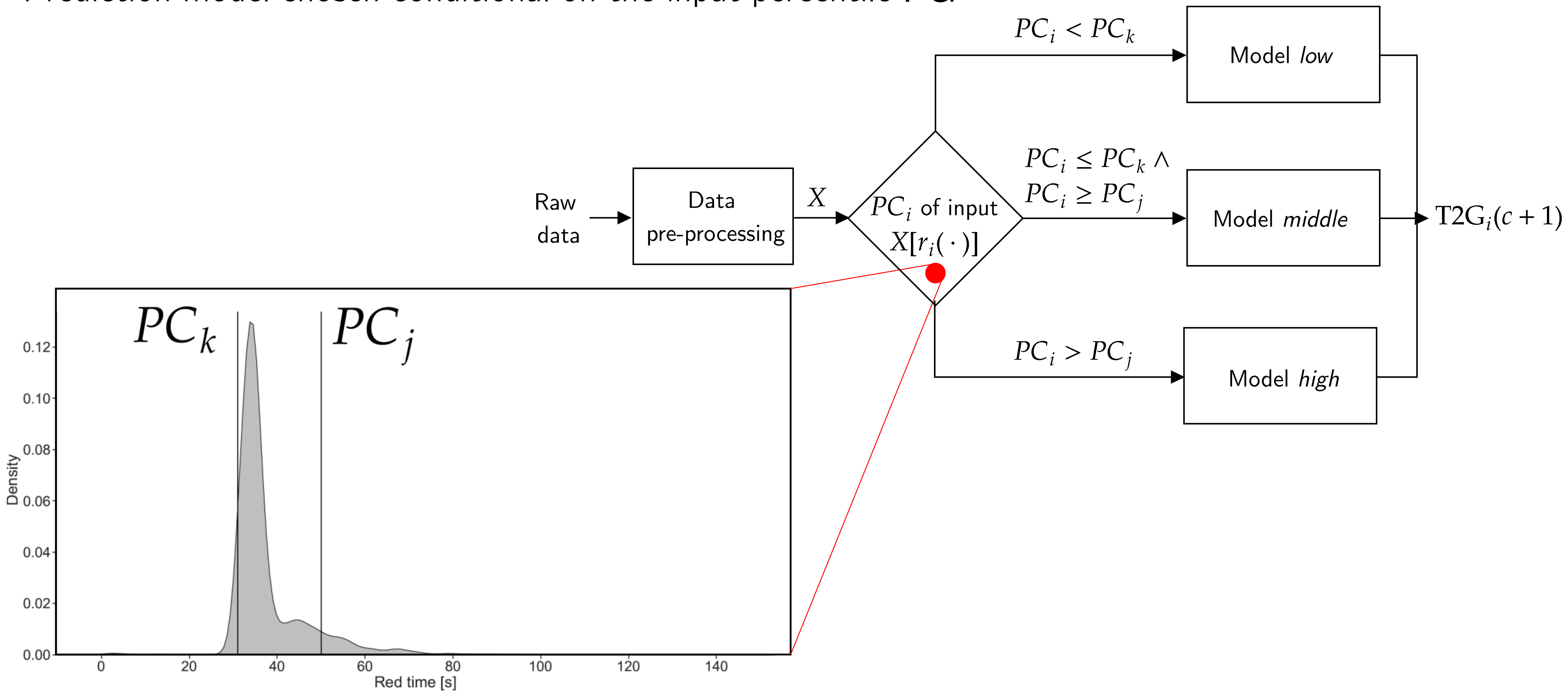
Framework methodology

- Prediction model chosen conditional on the input percentile **PCi**



Framework methodology

- Prediction model chosen conditional on the input percentile **PCi**



Framework methodology

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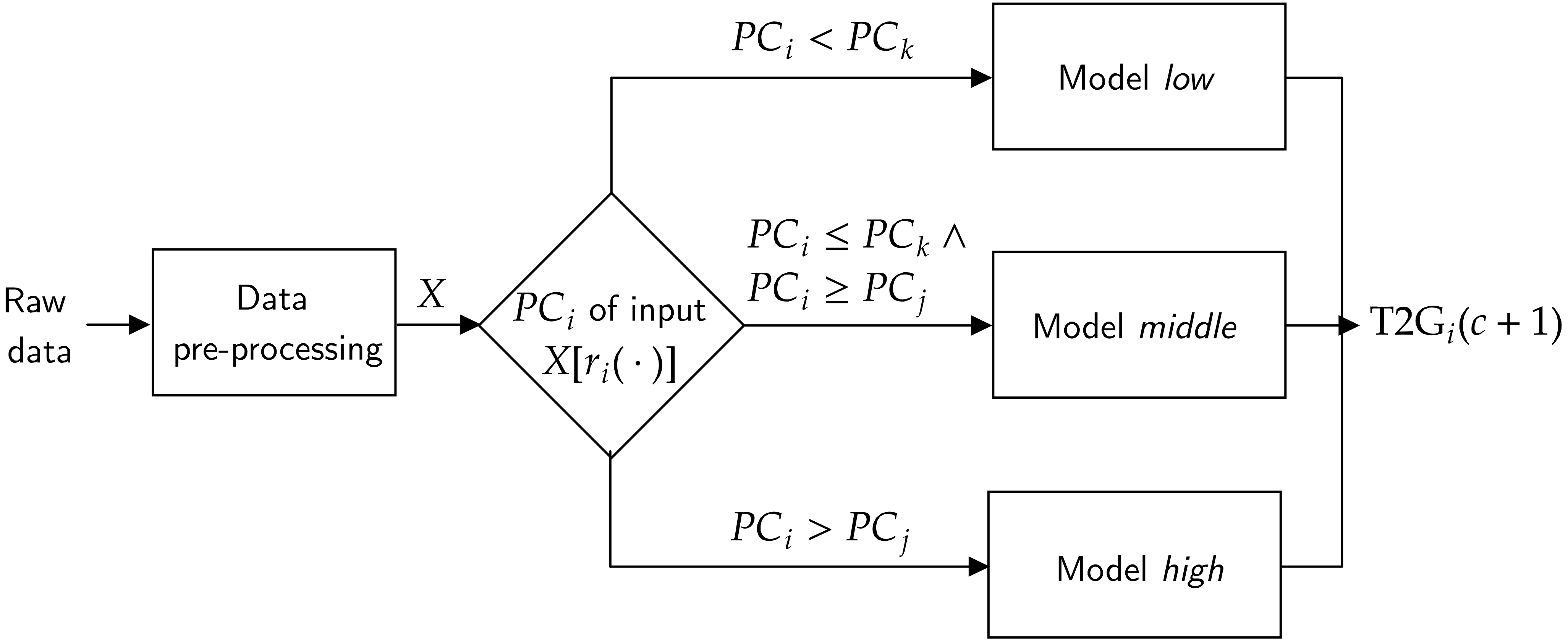


Model selection and performance metrics

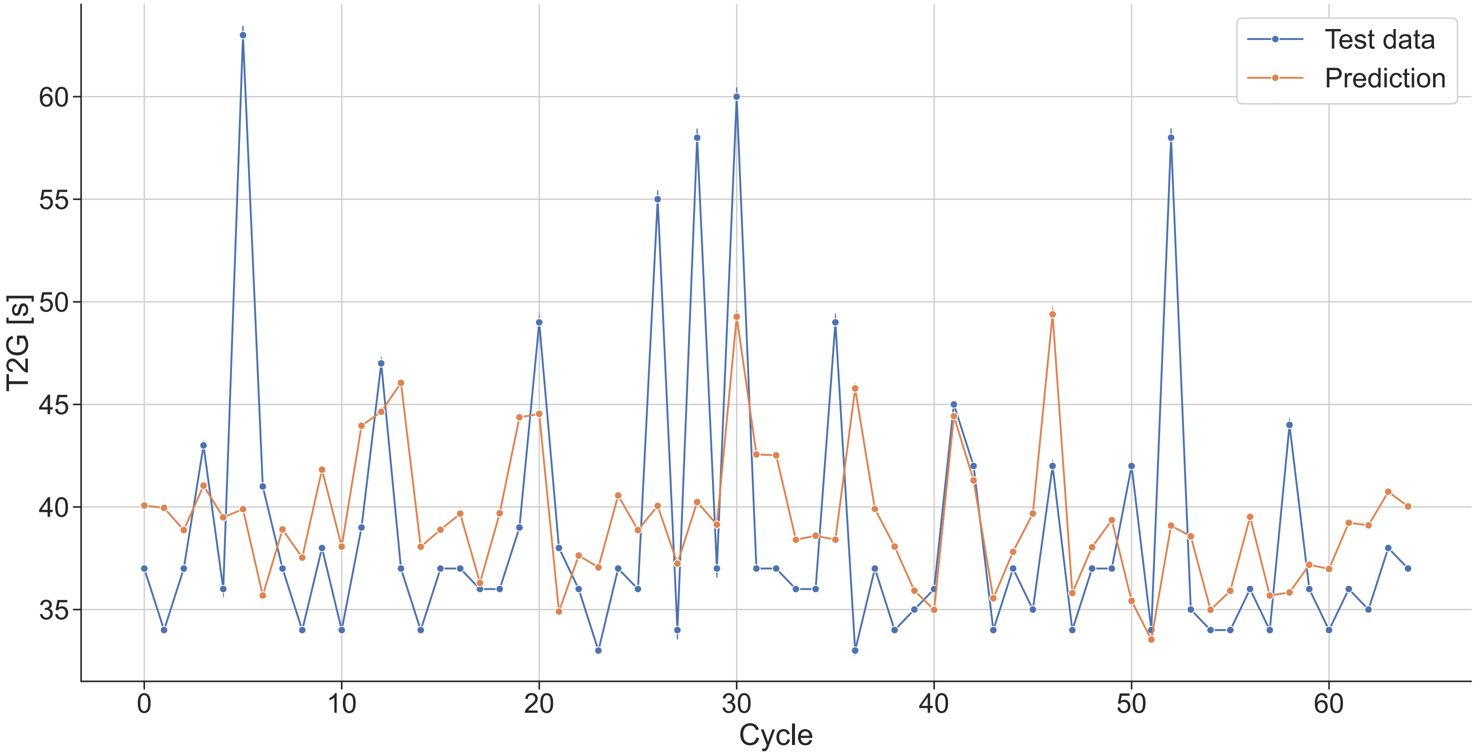
- Model selection
  - Multiple Linear regression (MLR)
  - Random forest (RF)
  - Random forest **with distribution split** (RFDS)

- Performance metrics
  - Mean Absolute Error
  - **Exact hit (EH)** – T2G is predicted with an error of 0 sec.
  - **Near misses (NM)** – T2G is predicted with an error of < 1 sec.

RESULTS

Results

Multiple Linear Regression (MLR)

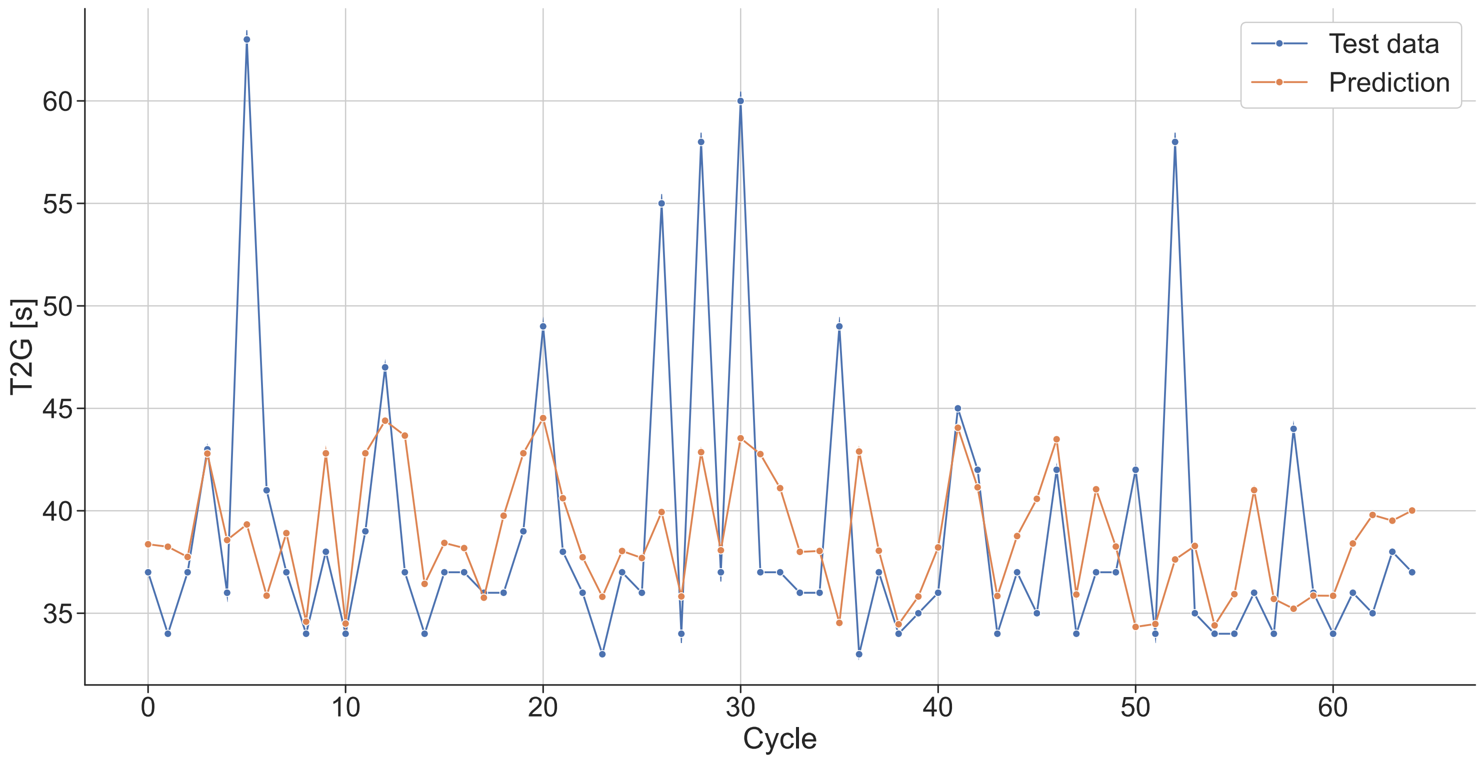


i	MLR MAE	EH[%]	NM[%]
1	4.75	5.07	16.94
2	4.23	13.29	42.60
3	4.63	11.70	35.42
4	**4.81**	**4.57**	**17.87**
5	4.90	4.15	16.50
...	...	...	...
12	63.12	0.88	1.32

Signals $i = \{12\}$ are only utilized for public transport.

Results

Random Forest (RF)

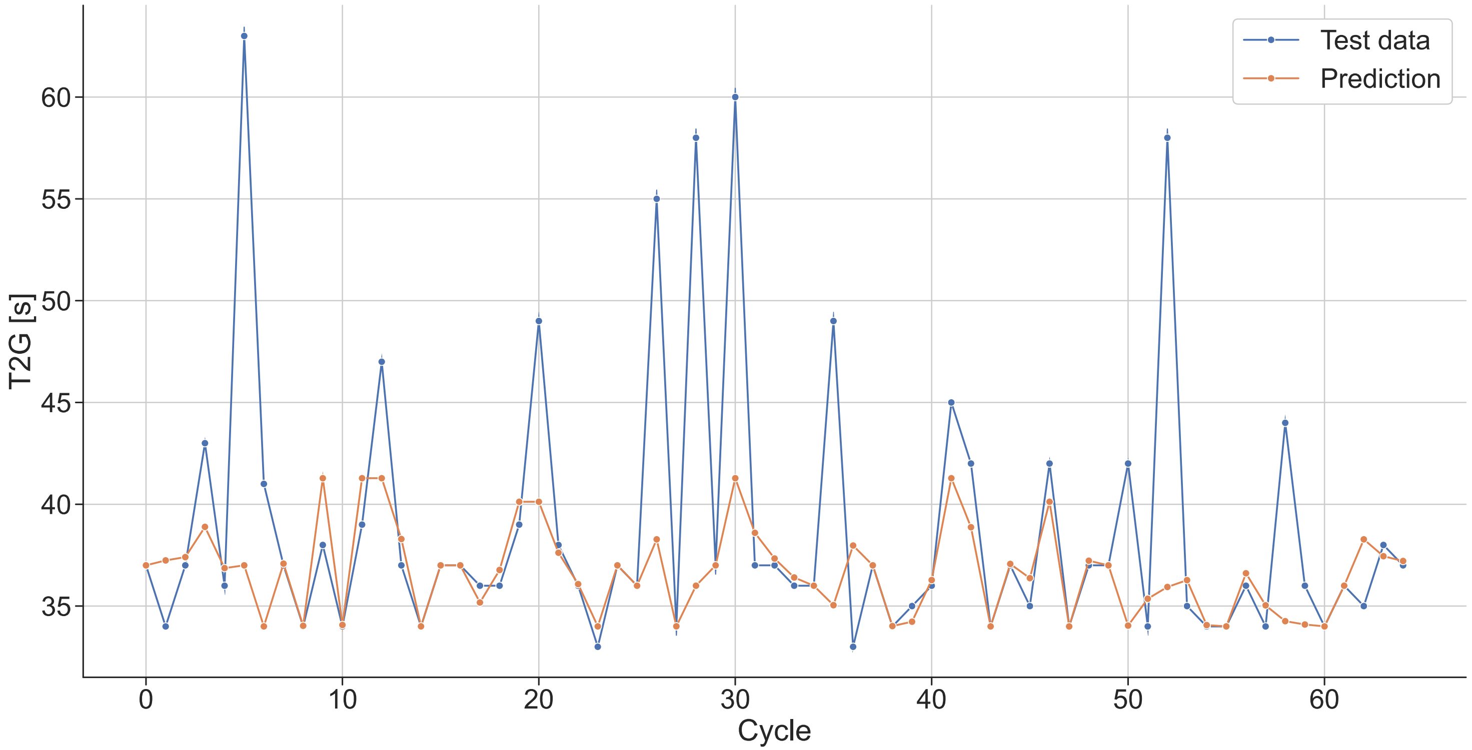


i	RF MAE	RF EH[%]	RF NM[%]
1	3.66	49.29	63.59
2	3.78	44.32	58.42
3	3.39	52.57	66.63
4	**4.54**	**6.60**	**26.80**
5	3.76	51.06	66.97
...	...	...	...
12	57.892	0.88	1.76

Signals $i = \{12\}$ are only utilized for public transport.

Results

Random Forest with distribution split (RFDS)

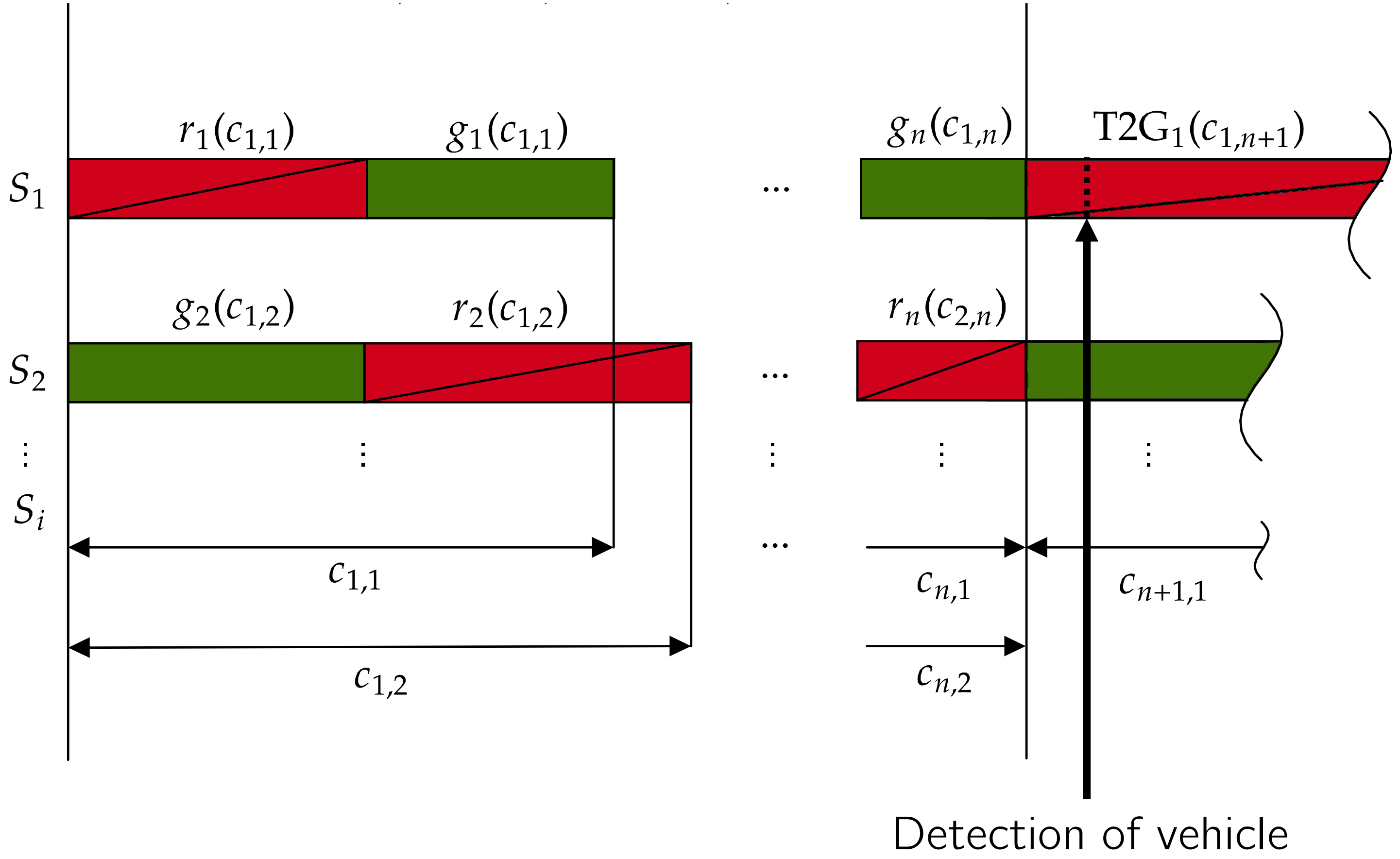


		RFDS	
i	MAE	EH[%]	NM[%]
1	3.44	50.00	66.02
2	3.50	44.02	61.56
3	3.44	50.92	64.99
4	**3.79**	**47.01**	**62.82**
5	4.02	47.01	62.82
...	...	...	...
12	58.32	0.88	4.41

Signals $i = \{12\}$ are only utilized for public transport.

Limitation of framework

- Model can not detect red time extensions that occur after the prediction
- Inferring this dynamic behavior can improve model robustness



CONCLUSION AND FUTURE WORK

Conclusion and future work

- Conclusion
  - T2G prediction framework for e.g., **SPaT message enhancement**
  - **Capturing of non-linear relationship** between traffic signal and loop detector data

- Future work
  - **Feature to model detections** occurring **after prediction**
  - Comparison to other machine learning candidates, e.g., XGBoost, LSTM
  - Test framework on **multiple** intersections (various characteristics)

ETH zürich

Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

Thank you very much for your attention!

Alexander Genser
Doctoral assistant, Traffic Engineering Group
gensera@ethz.ch

ETH Zurich
DBAUG, IVT
HIL F 34.2