Multimodal Performance Evaluation of Urban Traffic Control: A Microscopic Simulation Study

Natalie Sautter[1], Lisa Kessler[1], Danil Belikhov[1], Klaus Bogenberger[1]
[1] Chair of Traffic Engineering and Control, TUM School of Engineering and Design, Technical University of Munich, Germany

Abstract

Multimodality is a main requirement for future Urban Traffic Control (UTC). For cities and traffic engineers to implement multimodal UTC, a holistic, multimodal assessment of UTC measures is needed. This paper proposes a *Multimodal Performance Index (MPI)*, which considers the delays and number of stops of different transport modes that are weighted to each other. To determine suitable mode-specific weights, a case study for the German city Ingolstadt is conducted using the microscopic simulation tool SUMO. In the case study, different UTC measures (bus priority, coordination for cyclists, coordination for private vehicle traffic) are implemented to a varying extent and evaluated according to different weight settings. The MPI calculation is done both network-wide and intersection-specific. The results indicate that a weighting according to the occupancy level of modes, as mainly proposed in the literature so far, is not sufficient. This applies particularly to cycling, which should be weighted according to its positive environmental impact instead of its occupancy. Besides, the mode-specific weights have to correspond to the traffic-related impact of the mode-specific UTC measures. For Ingolstadt, the results are promising for a weighting according to the current modal split and a weighting with incentives for sustainable modes.

Keywords: microscopic simulation, multimodal traffic management, public transport priority, urban traffic control, traffic control strategies with active modes

1 Introduction

Urban Traffic Control (UTC) has evolved over the past 100 years, from first concepts of fixed-time traffic control to traffic-actuated control and adaptive network control systems that optimize traffic signal control for a network of coordinated stretches [Ham13; Pap03].

In Germany, Austria, and Switzerland, UTC is often conducted as traffic-actuated control on the intersection level with some coordinated road stretches. Also, adaptive network control systems such as MOTION and BALANCE have been tested [Bus01; Fri95; Mar14].

Due to a steady increase in private vehicle ownership in the past decades, cities aligned their UTC to private vehicle transport. Today, in the context of climate change and air pollution in cities, it is essential to promote environmentally friendly modes. In a survey from 2021, cities confirmed that multimodality is the main requirement for future UTC [Ili22a; Ili22b]. For a multimodal UTC it is essential to apply a multimodal performance evaluation. How the performance of multimodal transportation systems can be evaluated is investigated by the authors of [Kum13; Mis12; Zun18; Mat05; Jia20]. Based on the performance indicator used in the network control TRANSYT [Rob69; Rob86; Won95; Won02], Brilon and Wietholt [Bri13] proposed a multimodal performance index which weights different transport modes according to the occupancy level.

This paper revisits the concept of the *Multimodal Performance Index (MPI)* with the intention to promote sustainable transport modes. To determine suitable mode-specific weights, we conduct a case study for the German city of Ingolstadt in the microscopic simulation tool SUMO (Simulation of Urban Mobility) [Lop18]. We apply different combinations of UTC measures (bus priority, coordination for cyclists, and coordination for private vehicles) and evaluate them with regard to different weight distributions.

2 Scope and Methodology

We propose a novel methodology for the MPI calculation, which focuses on variable criteria relevant for politicians and traffic engineers to implement a future-oriented UTC. Therefore, we adapt the formula previously used in literature and research to better suit mode-specific weight settings. In previous literature, the occupancy level of transport modes determines their weights. This has been reasonable for private vehicles and public transport, but not for cycling, which was weighted low. Indeed, it should actively be promoted in terms of environmental impact and climate protection.

The MPI proposed in this paper is calculated according to

$$PI = \sum_{m} \sum_{e} \sum_{i} W_m \cdot W_e \cdot V_{m,e,i}, \tag{1}$$

where m denotes each mode of transport, e each evaluation parameter, i each considered link, W_m the weight per mode, W_e the weight per evaluation parameter and $V_{m,e,i}$ the recorded value per mode, evaluation parameter and link. Contrary to previous approaches [Bri13], we do not include the traffic volumes and link-specific weights. The choice and weighting of evaluation parameters is not in the scope of this paper. Therefore, we consider delay and number of stops and weight them in a ration of 60:1, analogously to [Bri13]. The scope of this paper is to determine suitable weights for public transport, cycling, and motorized traffic. The mode-specific weights sum up to 1. Pedestrians are not considered in this paper but left for future research. Besides, the spatial scope of the MPI calculation is examined in this paper by considering all links of an intersection (intMPI) as well as all links of the network (netMPI).

3 Case Study

3.1 Simulation Network

To assess the potential of the MPI as evaluation parameter for UTC and to determine suitable mode-specific weights, a case study in the microscopic simulation tool SUMO is conducted. Ingolstadt is a medium-large city in Bavaria with approx. 140,000 inhabitants (2021) [Ing22] that is rather private-vehicle oriented. According to a household survey in 2016, 59.0 % of the trips in Ingolstadt are performed by private vehicles, 21.0 % by bicycles, 12.6 % by walking and 7.4 % by public transport [Ing17]. Ingolstadt applies traffic-actuated control and bus priority at nearly all of its 160 signalized intersections. Additionally, 40 % to 50 % of signalized intersections are coordinated for motorized traffic.

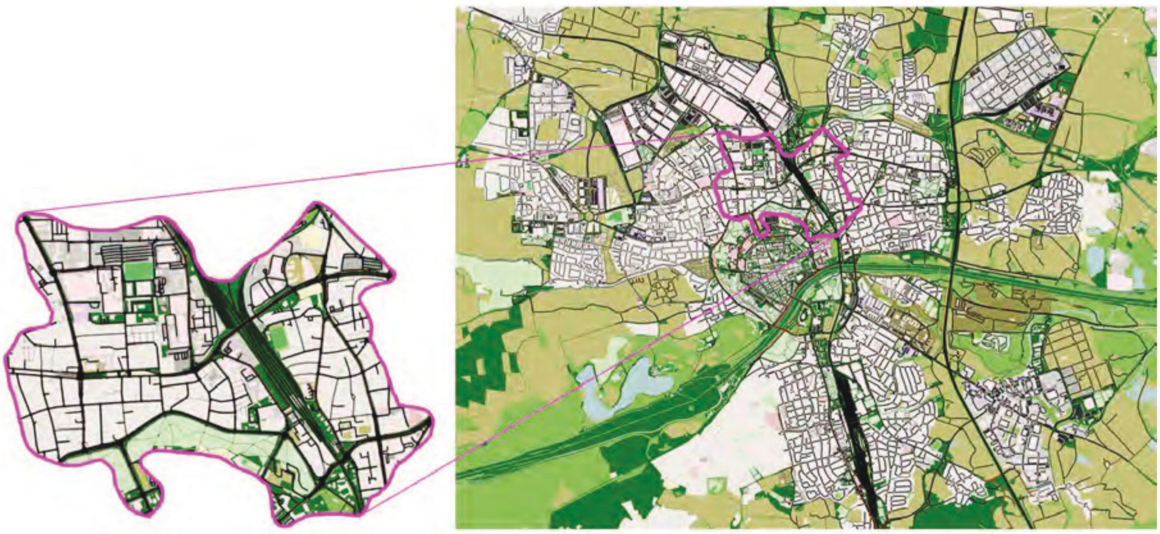


Figure 1: The SUMO network of Ingolstadt with the cut out part for the case study.

For our case study, a network section has been cut off the SUMO network, publicly available at `https://github.com/TUM-VT/sumo_ingolstadt`, see Figure 1. In this simulation, motorized traffic is well-calibrated based on statistical data and traffic counts from inductive loop sensors, whereas the bicycle demand is only roughly estimated. The traffic-actuated control is emulated by a fixed-time traffic control, that changes every hour based on the average green times observed in reality [Har22; Lan21]. Relevant data were retrieved from a representative weekday in September 2020. For the integration of public transport, we added 39 bus stops and 25 bus lines as it is in reality [INV22]. Major facts about the SUMO Simulation are summarized in Table 1.

Table 1: Major facts and settings for the case study in SUMO.

Network size	2.2 km x 1.6 km
Simulation period	Weekday at AM peak-hour (7:00 – 8:00)
Traffic demand (approximately)	public transport buses: 70 veh/h
	bicycles: 800 veh/h
	motorized vehicles: 750 veh/h

3.2 UTC Measures

The UTC measures implemented for this simulation are partially emulated from reality and partially contrived for the MPI case study to address all transport modes and to better scale the extent of UTC measures. Figure 2 shows all UTC measures implemented in this case study.

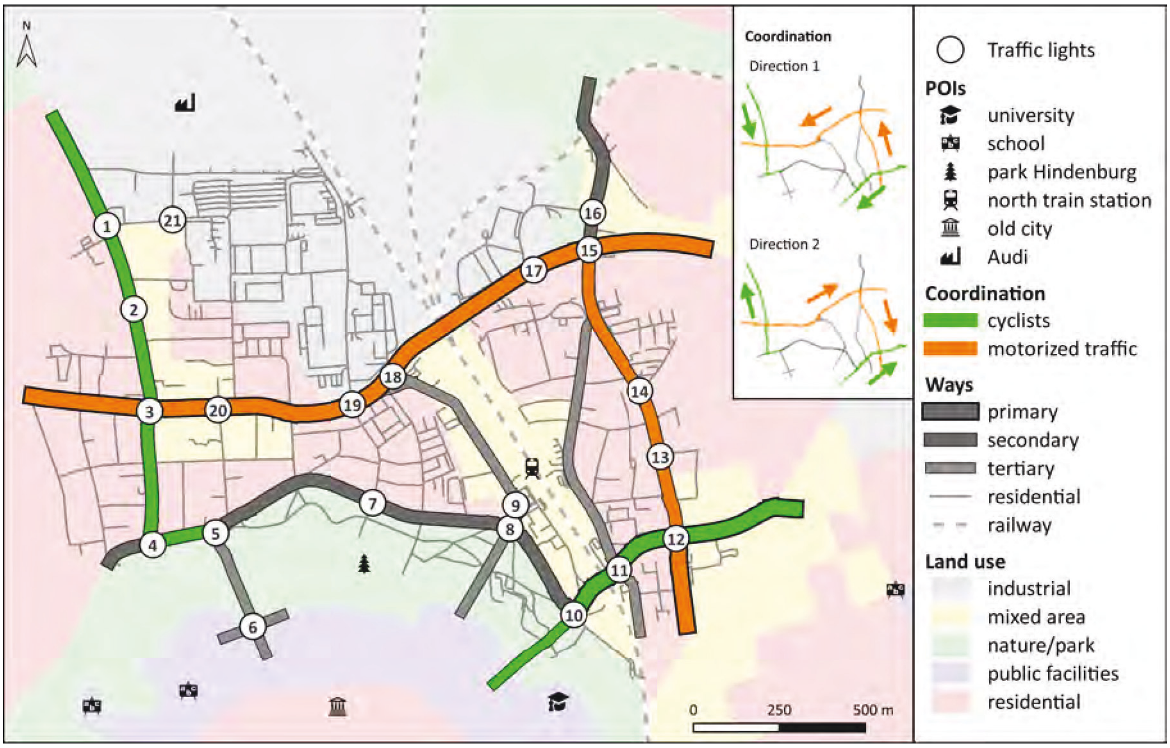


Figure 2: The cut-network for the MPI simulation study: Bus priority is implemented at every intersection; Coordination for cyclists is heading to park area and inner city; Coordination for motorized traffic is heading from residential areas and the motorway (east) to industrial areas; Coordination can be run in two different directions.

Bus priority is implemented for every signalized intersection, see Figure 2. Allowing buses to sign-in and sign-out, two detectors (according to [DLR22a]) per lane and direction are inserted in the SUMO simulation. To enable bus priority in the simulation, the interface

TraCI (Traffic Control Interface) [DLR22b] is used to continuously check for a bus detection and to adapt traffic signal control.

Four coordinations, two for vehicle traffic and two for cyclists, are implemented for the case study, see Figure 2. As recommended by the German guideline RiLSA, we chose progression speeds of 20 km/h and 50 km/h for cyclists and motorized traffic, respectively [FGS15]. Due to unequal distances in the network of Ingolstadt, it is not possible to run coordination in both directions at the same time. Therefore, two sets of directions have been implemented, see *Direction 1* and *Direction 2* in Figure 2. To implement the coordinations in SUMO, we unified the cycle times to 80 s and calculated the offsets for the signal programs. We implemented the coordinations for vehicle traffic and cyclists a compatible way with each other using the same offsets at intersections, where two coordinated stretches cross (intersections 3, 12, 15).

3.3 Simulation Scenarios and Weight Settings

We simulated ten different scenarios, i.e. combinations of mode-specific UTC measures, and evaluated them according to five different weight settings, see Table 2. Scenario 1 is the base scenario with no mode-specific UTC measure applied. In Scenarios 2 – 4, the mode-specific UTC measures are applied separately to full extend. As the coordination for cyclists and motorized traffic was designed as compatible, they are run in combination in Scenario 5 and 6 for *Direction 1 and 2*, respectively. At Scenario 7 and 8, bus priority is active at neither intersection so that it can be combined with coordination without disturbing it. At the two remaining scenarios, all UTC measures are run to full extend at the same time for *Direction 1 and 2*.

At weight setting A, modes are weighted according to the modal split from Ingolstadt without walking. At weight setting B, modes are weighted according to their average occupancy rate, similar to [Bri13]. As a plausible value for the average bus occupancy, we assume 5.75 during AM peak-hour on workdays. Assuming an occupancy for cyclists of 1 and an occupancy of 1.5 for motorized traffic [Fol19], the weight setting is set to (0.7 | 0.12 | 0.18). At weight setting C, modes are equally weighted, making it a good evaluation setting for comparative analyses. For weight setting D and E, the aspects of sustainability and occupancy are combined, one with a high weight for public transport and one with equal weights for public transport and cycling.

4 Results and Discussion

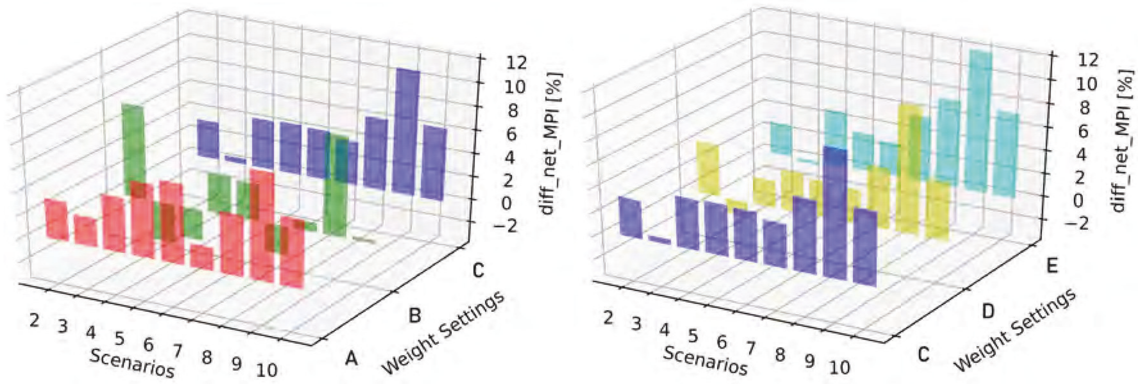
Table 2 displays the absolute values for the netMPI for all simulation scenarios and weight settings. The lower the netMPI, the better. As the netMPI is more meaningful in comparison, Figure 3 shows the percentage difference of the netMPI compared to Scenario 1 (no UTC measure), shortened by diffnetMPI. The higher the diffnetMPI, the better. Independently of the weight setting, applying all UTC measures (Scenario 9) leads to the best

Table 2: Results for netMPI, absolute values for different simulation scenarios and weight settings.

Scenarios		Weights				
		A	B	C	D	E
	public transport	0.085	0.7	0.333	0.5	0.4
	cycling	0.24	0.12	0.333	0.3	0.4
	private vehicle traffic	0.675	0.18	0.333	0.2	0.2
1.	No UTC measures	7356	4905	5773	5118	5183
2.	Only bus priority	7106	4514	5580	4886	5039
3.	Only cyclist coordination *Direction 1*	7174	5071	5745	5185	5201
4.	Only motorized traffic coordination *Direction 1*	7008	5036	5525	5000	4933
5.	Full coordination *Direction 1*	6894	4739	5522	4946	5014
6.	Full coordination *Direction 2*	6855	4749	5522	4960	5032
7.	Compatible combination bus priority and motorized traffic coordination	7209	5029	5553	4972	4889
8.	Compatible combination bus priority and cyclist coordination	6976	4867	5413	4851	4793
9.	Full combination *Direction 1*	6685	4483	5154	4566	4563
10.	Full combination *Direction 2*	6931	4891	5408	4865	4802

results and improves the netMPI by up to 10.8 % compared to no UTC measures (Scenario 1). When mode-specific measures are implemented isolated, the highest associated mode-specific weights also achieve the best result, e.g. bus priority (Scenario 2) has its highest diffnetMPI value (8.0 %) at the highest weight for public transport (weight setting B). At equal weight distribution (weight setting C), the netMPI improves for all scenarios, i.e. all possible UTC measure combinations. However, coordination for cycling (Scenario 3) performs significantly worse than other measures. This suggests that the mode cycling must be weighted highly to ensure that cyclist coordination is implemented in reality. Weighting according to the occupancy level (weight setting 2) is also not sufficient as it is the worst performing weight setting with even negative diffnetMPI values for Scenario 3 and 4 (-3.4 % and -2.7 %). These results suggest that cycling has to be weighted higher and public transport lower. A weighting according to the current modal split (weight setting 1) provides good and meaningful results, but is not conducive to promote sustainable modes. The weight settings D and E, considering occupancy and sustainability of the modes, perform well for all scenarios except the cyclist coordination (Scenario 3).

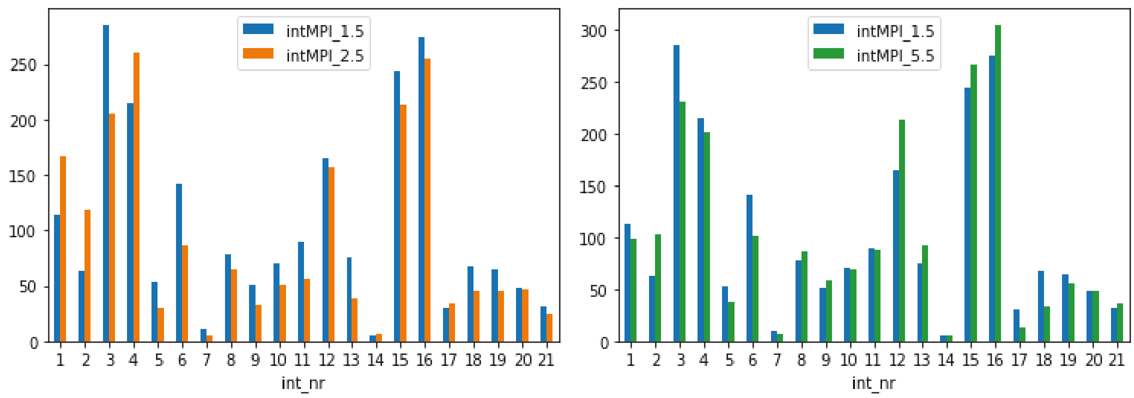
To gain a more local insight on the effect of UTC measures, Figure 4 displays the intMPI in absolute values before and after implementing bus priority (a) and full coordination (b).



(a) Weight settings A-C. **(b)** Weight settings C-E.

Figure 3: Results for netMPI, percentage difference to simulation scenario 1 (no UTC measures) for different weight settings.

The intersection numbers correspond to those from Figure 2. 5 of 21 intersections have a worse intMPI after bus priority, meaning that the negative influence on cyclists and private vehicles is much higher than the positive effect on buses. At full coordination, 8 of 21 intersections have a worse intMPI than before implementation. After precluding errors in the implementation of the UTC measures, there are two options to deal with local deterioration of the intMPI: changing the weight setting locally or excluding the intersection from the UTC measure.



(a) Effect of bus priority (Scenario 2 compared to Scenario 1). **(b)** Effects of full coordination (Scenario 5 compared to Scenario 1).

Figure 4: Selected results for intMPI, absolute values for weight setting 5.

5 Conclusion

A sustainable and future-oriented Urban Traffic Control (UTC) requires a multimodal and holistic assessment of its performance. This paper presents an approach of an *Multimodal Performance Index (MPI)* calculation including the transport modes public transport, cycling, and private motorized vehicles. In a case study, we investigated different scenarios and weight settings. Our conclusion is that mode weights according to the occupancy level are not sufficient. Instead, modes should be weighted according to the effectiveness of the UTC measures addressing them and their environmental footprint to promote them accordingly, specifically cyclists. This paper also shows that it is beneficial to conduct a network-wide and an intersection-specific MPI calculation: the netMPI to determine weight settings and the intMPI to verify weight settings and the functionality of UTC measures. Our next steps include the applicability to other networks than in our case study. We expect that characteristics such as network and intersection layout and demand levels will also play a role at weight setting. Besides, further research can address the suitability of evaluation parameters for the different modes. For public transport and cycling, other evaluation parameters than delay and number of stops might be efficient.

Acknowledgments

This work has been carried out as part of the KIVI research project (Artificial Intelligence in the Transportation System of Ingolstadt), which is funded by the German Federal Ministry of Transport and Digital Infrastructure (Funding ID: 45KI05A011).

References

[Bri13] W. Brilon and T. Wietholt: "Experiences with Adaptive Signal Control in Germany". In: *Transportation Research Record: Journal of the Transportation Research Board* 2356.1 (Jan. 2013), pages 9–16. ISSN: 0361-1981. DOI: 10.1177/0361198113235600102.

[Bus01] F. Busch and G. Kruse: "MOTION for SITRAFFIC - a modern approach to urban traffic control". In: *2001 IEEE International Conference on Intelligent Transportation Systems Conference (ITSC)*. Institute of Electrical and Electronics Engineers, Nov. 2001, pages 61–64. DOI: 10.1109/ITSC.2001.948630.

[DLR22a] *SUMO Documentation: Simulated Detectors*. German Aerospace Center, 2022. URL: https://sumo.dlr.de/docs/Simulation/Output/#simulated_detectors.

[DLR22b] *SUMO Documentation: TraCI*. German Aerospace Center, 2022. URL: https://sumo.dlr.de/docs/TraCI.html.

[FGS15] *Richtlinien für Lichtsignalanlagen – Lichtzeichenanlagen für den Straßenverkehr*. FGSV Verlag, 2015. ISBN: 978-3-93-971591-7.

[Fol19] R. Follmer and D. Gruschwitz: "Mobility in Germany – MiD short report". In: (Sept. 2019). URL: https://www.bmvi.de/SharedDocs/DE/Anlage/G/mid-2017-kurzreport.pdf.

[Fri95] B. Friedrich: "Balance and Control: Methods for traffic adaptive control". In: *World Congress on Intelligent Transport Systems*. Volume 5. Yokohama-shi, Japan, Nov. 9–11, 1995. URL: https://trid.trb.org/view/689763.

[Ham13] A. Hamilton, B. Waterson, T. Cherrett, A. Robinson, and I. Snell: "The evolution of urban traffic control: changing policy and technology". In: *Transportation Planning and Technology* 36.1 (Feb. 2013), pages 24–43. ISSN: 0308-1060. DOI: 10.1080/03081060.2012.745318.

[Har22] M. Harth, M. Langer, and K. Bogenberger: "Automated Calibration of Traffic Demand and Traffic Lights in SUMO Using Real-World Observations". In: *SUMO Conference Proceedings*. Volume 2. TIB Open Publishing, June 2022, pages 133–148. DOI: 10.52825/scp.v2i.120.

[Ili22a] M. Ilic, N. Sautter, M. Margreiter, A. Loder, and K. Bogenberger: "Changing Strategic Alignments in European Urban Traffic Control – Requirements for Future Developments". In: *10th Symposium of the European Association for Research in Transportation*. 2022. URL: https://transp-or.epfl.ch/heart/2022/abstracts/158.pdf.

[Ili22b] M. Ilic, N. Sautter, M. Margreiter, A. Loder, and K. Bogenberger: "Revisiting Urban Traffic Control in Austria, Germany and Switzerland – Requirements for Future Developments". In: *Transportation Research Board - 101st Annual Meeting 2022*. Washington, DC, Jan. 2022. URL: https://www.researchgate.net/publication/358277101_Revisiting_Urban_Traffic_Control_in_Austria_Germany_and_Switzerland_-_Requirements_for_Future_Developments.

[Ing17] *Traffic Development Plan 2025 of the City of Ingolstadt*. City of Ingolstadt, 2017. URL: www.ingolstadt.de/output/download.php?fid=2789.1089.1.PDF.

[Ing22] *Current numbers and statistics*. City of Ingolstadt, 2022. URL: www.ingolstadt.de/Rathaus/Aktuelles/Zahlen-Daten/Aktuelle-Statistiken/.

[INV22] *Timetable 2022*. Ingolstädter Verkehrsgesellschaft mbH, INVG, 2022. URL: https://www.invg.de/timetable_2022.

[Jia20] W. Jiang: "Multi-criteria and Multi-modal Evaluation of Traffic Signal Control". PhD thesis. Technical University of Darmstadt, 2020. URL: https://tuprints.ulb.tu-darmstadt.de/17416/1/Dissertaton_publication_final_20210102.pdf.

[Kum13] P. P. Kumar, M. Parida, and M. Swami: "Performance Evaluation of Multimodal Transportation Systems". In: *Procedia – Social and Behavioral Sciences* 104 (Dec. 2013), pages 795–804. ISSN: 1877-0428. DOI: 10.1016/j.sbspro.2013.11.174.

[Lan21] M. Langer, M. Harth, L. Preitschaft, R. Kates, and K. Bogenberger: "Calibration and Assessment of Urban Microscopic Traffic Simulation as an Environment for Testing of Automated Driving". In: *2021 IEEE International Conference on Intelligent Transportation Systems Conference (ITSC)*. Piscataway, NJ: Institute of Electrical and Electronics Engineers, Sept. 2021, pages 3210–3216. ISBN: 978-1-72-819142-3. DOI: 10.1109/ITSC48978.2021.9564743.

[Lop18] P. A. Lopez, M. Behrisch, L. Bieker-Walz, J. Erdmann, Y.-P. Flötteröd, R. Hilbrich, L. Lücken, J. Rummel, P. Wagner, and E. Wiessner: "Microscopic traffic simulation using SUMO". In: *21st International Conference on Intelligent Transportation Systems (ITSC)*. Edited by W.-B. Zhang, A. M. Bayen, J. J. S. Medina, and M. J. Barth. Institute of Electrical and Electronics Engineers, Nov. 2018, pages 2575–2582. DOI: 10.1109/itsc.2018.8569938.

[Mar14] M. Margreiter, S. Krause, H. Twaddle, and J. Lüssmann: "Evaluation of Environmental Impacts of Adaptive Network Signal Controls Based on Real Vehicle Trajectories". In: *Transportation Research Procedia* 4 (2014), pages 421–430. ISSN: 2352-1465. DOI: 10.1016/j.trpro.2014.11.032.

[Mat05] E. C. Matsoukis: "Calculating the performance index for isolated and coordinated traffic signal controlled intersections". In: *Urban Transport* 77 (2005), pages 681–690. ISSN: 1743-3509. URL: https://www.witpress.com/Secure/elibrary/papers/UT05/UT05066FU.pdf.

[Mis12] S. Mishra, T. F. Welch, and M. K. Jha: "Performance indicators for public transit connectivity in multi-modal transportation networks". In: *Transportation Research Part A: Policy and Practice* 46.7 (Aug. 2012), pages 1066–1085. ISSN: 0965-8564. DOI: 10.1016/j.tra.2012.04.006.

[Pap03] M. Papageorgiou, C. Kiakaki, V. Dinopoulou, A. Kotsialos, and Y. Wang: "Review of road traffic control strategies". In: *Proceedings of the IEEE*. Volume 91. 12. Institute of Electrical and Electronics Engineers, Dec. 2003, pages 2043–2067. DOI: 10.1109/JPROC.2003.819610.

[Rob69] D. I. Robertson: *TRANSYT: A Traffic Network Study Tool*. Technical report LR 253. 1969.

[Rob86] D. I. Robertson: "Research on the TRANSYT and SCOOT Methods of Signal Coordination". In: *ITE Journal* 56.1 (1986), pages 36–40. ISSN: 0162-8178.

[Won02] S. C. Wong, W. T. Wong, C. M. Leung, and C. O. Tong: "Group-based optimization of a time-dependent TRANSYT traffic model for area traffic control". In: *Transportation Research Part B: Methodological* 36 (May 2002), pages 291–312. ISSN: 0191-2615. DOI: 10.1016/s0191-2615(01)00004-2.

[Won95] S. C. Wong: "Derivatives of the performance index for the traffic model from TRANSYT". In: *Transportation Research Part B: Methodological* 29.5 (Oct. 1995), pages 303–327. ISSN: 0191-2615. DOI: 10.1016/0191-2615(95)00012-3.

[Zun18] N. Zuniga-Garcia, H. W. Ross, and R. B. Machemehl: "Multimodal Level of Service Methodologies: Evaluation of the Multimodal Performance of Arterial Corridors". In: *Transportation Research Record: Journal of the Transportation Research Board* 2672.15 (May 2018), pages 142–154. issn: 0361-1981. doi: 10.1177/0361198118776112.

Corresponding author: Natalie Sautter, Chair of Traffic Engineering and Control, TUM School of Engineering and Design, Technical University of Munich, Germany, e-mail: natalie.sautter@tum.de