

Advanced Methods for Measurement and Control in Urban Road Traffic Networks

Overview of Ph.D. Thesis

by Tamás Tettamanti

Supervisor:
Dr. István Varga



M Ű E G Y E T E M 1 7 8 2

Department of Vehicle and Transportation Control
Budapest University of Technology and Economics

2013

1 Motivation

The growth of the motorization rate and the resulted external consequences generates real challenges for the traffic planners and traffic engineers. Traffic congestion is one of the primary negative impacts which became everyday occurrence in the last decades. The capacity of the traffic networks saturates during rush hours. Furthermore, today's demand cannot be always suitably satisfied even if traffic-responsive traffic signaling is applied. As result, external effects appear causing additional costs for the society.

To assure the sustainable mobility as well as a satisfying life quality in metropolitan areas, complex management strategies together with network-wide traffic control are needed. The first step of the design process of an efficient traffic management system is to determine the goals to achieve. Secondly, the applicable tools (algorithms) and infrastructure must be investigated. Basically, the traffic management consists of proper traffic measurement, modeling, and control (see Fig. 1) [TV11a].

Accordingly, the thesis investigates advanced methods applicable in this field. Traffic measurement and estimation, modeling as well as optimal and robust control of urban road traffic are the most important parts of my research. The achieved research results serve as practical methods for efficient capacity exploitation in the urban transportation.

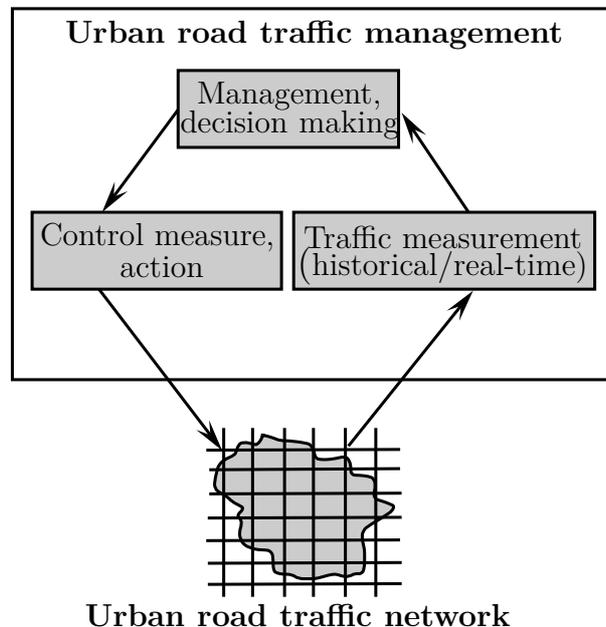


Figure 1: The structure of the urban road traffic management

2 Main Objectives and Method of Research

The aim of the research of advanced traffic applications provided in the thesis is to contribute to the better understanding and design of urban traffic processes. According to this goal, four problems were chosen for which new solutions are proposed. Basically, the research scope focuses on measurement and control in the field of traffic engineering. The consistency of the thesis contributions is represented by the relation between the investigated problems. The research objectives are summarized below.

1. Algorithm for cost effective vehicle queue length estimation in urban link.
2. Methodology for route choice, O-D matrix and traffic flow estimation in urban road traffic network based on mobile signaling events.
3. Algorithm for distributed MPC control scheme for real-time signal split optimization in urban road traffic network.
4. Robust traffic control algorithm for large-scale urban network taking queue and demand uncertainties into consideration with treatable computational complexity.

The given solutions of the proposed problems reflect the thesis results (summarized in the next section).

The traffic control can be identified as a traditional feedback control problem with sensors, control algorithms, and actuators [TVB07, VKLT08, Tet08]. The methods can be efficiently borrowed from the modern control theory. Consequently, the thesis applies several tools of the control theory, such as state space representation, Kalman Filter, predictive and robust control [BG08]. Additionally, the applicability of the mobile phone events for traffic prediction is also investigated, which is a popular research direction of our days [CWB08].

During my research work, beside the theoretical control tools I always concentrated on the validation and the representation of the research results. Therefore, an integrated simulation environment (see Fig. 2) was developed specifically for advanced road traffic control design [TLV08a, TLV08b, TV12a]. The applied simulation framework consists of mathematical optimization tools (MATLAB, C++), traffic simulators (VISSIM, VISUM), and GIS software (Quantum GIS).

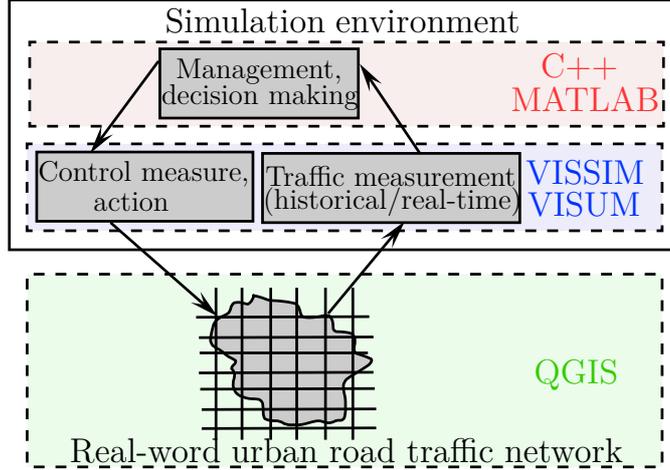


Figure 2: The complete simulation environment

3 Contributions of the Thesis

Thesis 1

Two cost-effective methods have been elaborated for vehicle queue length estimation, applicable in signalized urban traffic networks. The proposed techniques involve the Kalman Filtering algorithm and the appropriate use of the vehicle conservation-law in urban road link. The methods can be applied with two different measurement configurations; either two detectors or a single detector per link. Both configurations are able to provide efficient traffic estimation. The previous one is valid both in undersaturated or saturated traffic conditions, and the latter one with saturated traffic condition. [TV10b, TV10c, LTV11]

The method for real-time vehicle queue estimation based on Kalman Filtering [Kal60] was introduced by [VPW08]. The method applies three detectors (upstream, downstream and middle positions) per link. The state and the measurement equation of the Kalman Filter are given as follows:

$$x(k+1) = x(k) + T(q_{in}^m(k) - q_{out}^m(k)) + Tv(k), \quad (1)$$

$$y(k) = x(k) + z(k) \frac{\Delta n}{L^{eff}} = \frac{\Delta n}{L^{eff}} o_T^m(k), \quad (2)$$

where $x(k)$ is the vehicle number in the link, T the sample time, $q_{in}(k)$ and $q_{out}(k)$ the inflow and outflow traffic, $v(k)$ and $z(k)$ the state and measurement noise, L^{eff} the average effective vehicle length, Δ the link length, n

the lane number, and $o_T^m(k)$ is the measured average time occupancy. As improvement of the method, the modification of the measurement configuration is proposed which also means the use of different state equation (1); i.e. modified estimation methods with only two or one detector per link.

If the turning rates of the intersections are known (e.g through appropriate estimation [KVB04]), the outflow traffic can be calculated from the upstream detector measurements. Thus, downstream loops can be elimi-

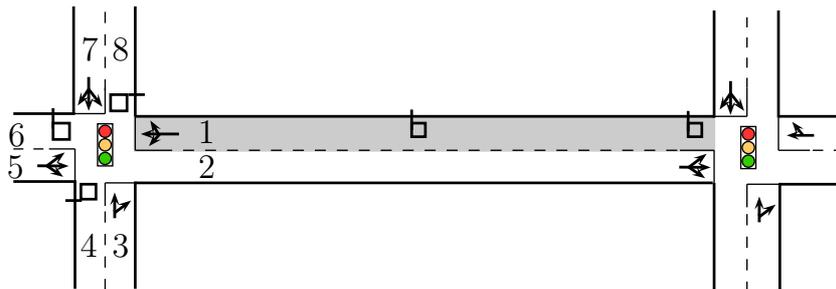


Figure 3: Measurement configuration with two detectors

nated (see Fig. 3), and state equation (1) of the Kalman Filter is redefined:

$$x_1(k+1) = x_1(k) + T(q_1^m(k) - \gamma_4 q_4^m(k) - \gamma_6 q_6^m(k) - \gamma_8 q_8^m(k)) + T v_1(k), \quad (3)$$

where $\gamma(k)$ is the ratio of the exiting traffic from link 1 in proportion to the whole entering traffic of the corresponding link. The estimation method with two detectors per link can be applied either in saturated or undersaturated traffic conditions [GP63]. At the same time, a single detector per link can also be sufficient with the assumption of saturated traffic. Based on the known saturation flow (S), green times (u), and turning rates (β), the inflow and outflow can be determined without sensors. The measurement configuration in this case is illustrated by Fig. 4. State equation (1) of the

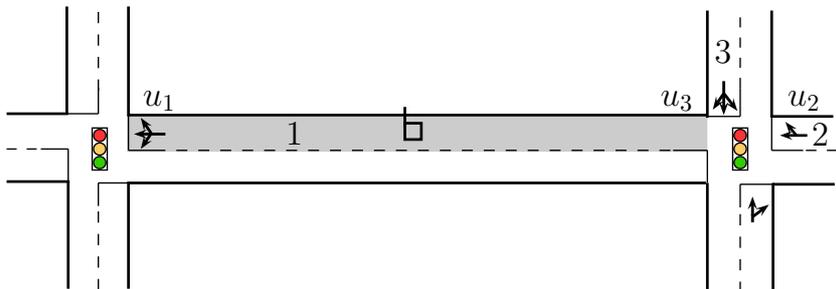


Figure 4: Measurement configuration with a single detector

Kalman Filter is given now as follows:

$$x_1(k+1) = x_1(k) + u_3(k)\beta_3 S_3 + u_2(k)\beta_2 S_2 - u_1(k)S_1 + T v_1(k). \quad (4)$$

The proposed techniques can be applied with loop detectors or other sensors measuring the traffic flow at cross-sections of the road link. The main result of the presented methods is characterized by the cost effectiveness as a pair of detectors or even a single detector may be sufficient for reliable queue length determination in signalized network.

Thesis 2

A methodology has been elaborated for macroscopic traffic flow estimation based on cellular phone signaling events in urban road traffic networks. The concept is based on the practical approach that transportation modeling can be adapted to the location areas and cells of the mobile network. The O-D matrix can be defined by the appropriate measurement and filtering of the signaling events occurred within the corresponding location area. The traffic assignment based on the identified O-D matrix can be further improved by the help of travel time data obtained from handover sequences. The method utilizes the measured travel times as additional constraints in the optimization problem of the assignment to obtain more reliable results.

[TDV12, TV12b, LTV12]

Signaling data of cellular phones can be used as valuable information in the field of road traffic measurement and forecasting or even traffic control. As the terminals automatically report handovers (HO) and location area updates (LAU) to the communication system, the cell phone operator may exploit these data. The possible applications of the HO/LAU reports have been widely investigated, e.g. [CDLLR11, CWB08, VDRW09].

As the preliminary step of the classical four-step system model for urban transportation, the main nodes of the traffic network have to be defined which serve as origins and destinations. The transportation network description can be adapted to the cellular network. The main idea is that the O-D nodes are defined in the boundary cells of the corresponding location area (an example is shown by Fig. 5). This concept is needed as HOs are only reported when the mobile phone is in call. Contrarily, in idle mode LAU event always occurs when a terminal passes the LA boundary. Therefore, location area can be efficiently considered for O-D flow estimation.

If the reliable travel times are available from the cellular signaling events, the traditional traffic assignment problem can be further improved. By applying the Voronoi tessellation [CGW⁺08] based network description and

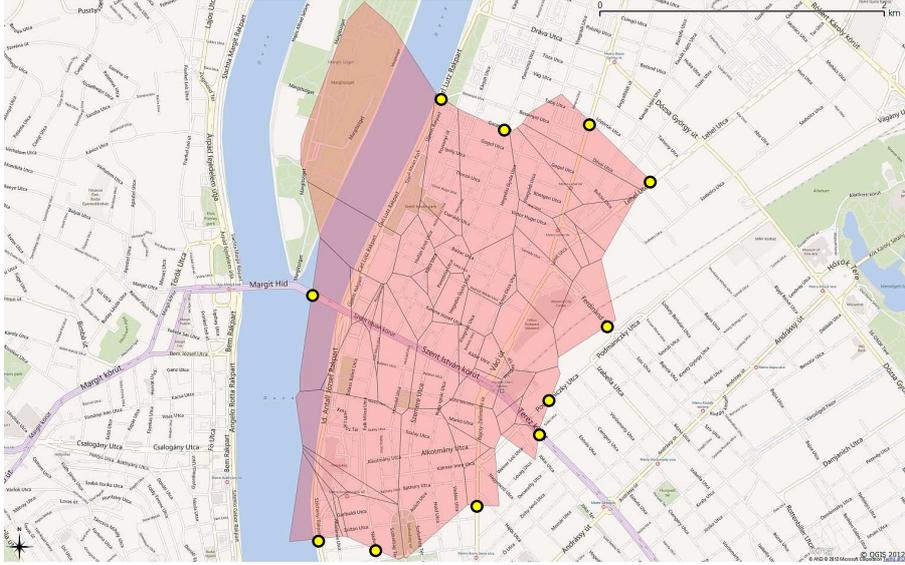


Figure 5: A location area with main nodes in Budapest

the aggregated HO/LAU events, the travel times of the terminals can be calculated [LTV12]. The volume-delay function of the measured links can be restricted according to the measured travel times. This means that the following constraints have to be added to the assignment problem:

$$t_a^m(1 - \Delta_a) \leq t_a \leq t_a^m(1 + \Delta_a), \quad (5)$$

where t_a^m denotes the average measured travel time on edge a and Δ_a an uncertainty term. To summarize the proposed traffic flow estimation the following algorithm is provided.

1. Collect all HO/LAU events concerning the LA.
2. Filter the signaling events to obtain more reliable data.
3. Discover the O-D trips from the signaling data.
4. Do traffic assignment on the network.
5. Determine the most probable paths for the terminals generating HO sequences by the help of the previously achieved assignment.
6. By using the path travel times of terminals with HOs, determine the average measured travel time (t_a^m) for the corresponding links.
7. Do traffic assignment with additional constraints (5) concerning the links with observed travel times.

Thesis 3

An efficient distributed MPC design has been elaborated for urban road traffic control. The proposed technique is a traffic-responsive signal control, applicable in urban traffic networks under saturated traffic conditions. The control algorithm applies the Lagrange multiplier method and the projected Jacobi iteration to perform parallel computation among the traffic controllers realizing a distributed solution.

[TV09b, TV09a, TV10a, TVP10, LTV11]

[Var06], [TV09c], [TV09d] published the centralized MPC [Mac02] based urban traffic control. The control inputs are computed by minimizing quadratic objective $J(k)$ over a finite prediction horizon:

$$\begin{aligned} & \min_{u(k+i-1|k)} J(k), \\ & \text{subject to } u(k+i-1|k) \in \mathbb{U}, \\ & \quad \quad \quad x(k+i|k) \in \mathbb{X}, \end{aligned} \tag{6}$$

where \mathbb{U} and \mathbb{X} denote the polyhedral constraint sets if the system dynamics is restricted along its trajectory. As an improvement of the control method,

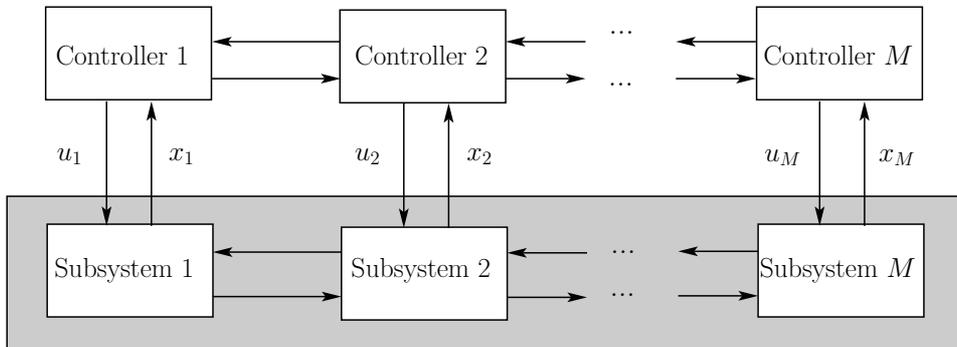


Figure 6: Distributed control architecture

a distributed realization (see Fig. 6) is proposed in which the computational tasks are divided among the local traffic controllers with global communication. The minimization of $J(k)$ represents a general quadratic optimal problem and can be defined as:

$$\begin{aligned} & \min_{\mathbf{u}} J(k) = \frac{1}{2} \mathbf{u}^T \Phi \mathbf{u} + \beta^T \mathbf{u}, \\ & \text{subject to } \mathbf{F} \mathbf{u} - \mathbf{h} \leq 0. \end{aligned} \tag{7}$$

\mathbf{u} is the control input vector for K horizons. Φ is a constant matrix, and β^T is a time-varying vector. Inequality $\mathbf{F}\mathbf{u} - \mathbf{h} \leq 0$ incorporates the green time constraints. By using the duality theory [BT97], primal problem (7) can be reformulated into the Lagrange dual standard form, and reduced to the solution of the following system of linear equations under the nonnegativity condition:

$$P\lambda = w, \quad (8)$$

where P and w are the combination of Φ , β , \mathbf{F} , and \mathbf{h} . The projected Jacobi iteration is applied to solve Eq. (8) with $\lambda_j \geq 0$ [BT97]:

$$\lambda_j(t+1) = \max \left\{ 0, \lambda_j(t) - \frac{\kappa}{p_{jj}} \left(w_j + \sum_{k=1}^m p_{jk} \lambda_k(t) \right) \right\}, \quad j = 1, 2, \dots, m, \quad (9)$$

where $\kappa > 0$ is the stepsize parameter and p the corresponding element of matrix P .

By exploiting the iteration based solution of dual problem (8), the MPC problem can be implemented in a distributed way with parallel computation. In a large-scale urban traffic network, the nodes $i = 1, 2, \dots, M$ can be represented by the CPUs of the junction traffic controllers. The concept consists of splitting global iteration process (9) into smaller problems according to the M nodes. The main idea is that the solution of subproblem i is carried out with a reduced set of optimization variables. The final solution is achieved as an increasingly accurate approximate solution. Once final solution λ^* of iteration (9) is achieved, the solution of the MPC can be directly calculated, i.e. the optimal green time splits.

Thesis 4

A real-time robust control has been elaborated for urban road traffic networks. The applied dynamic representation is based on the store-and-forward paradigm augmented by state and demand uncertainties. The traffic-responsive signal control is formulated in a centralized rolling horizon fashion. For efficient online solution of the problem, SDP optimization is suggested. The proposed technique is able to explicitly handle model-mismatches, and applicable under saturated as well as oversaturated traffic conditions.

[TVP⁺11, TV11b, LTV11]

The advanced traffic management is usually based on a reliable model of the system. The traffic models, however, may be biased by non-measurable entering or exiting traffic flows causing uncertainties in the dynamic representation. In a general urban road link (see Fig. 7) between two signalized intersections (M and N) different potential traffic streams can be observed. g and h represent entering and exiting vehicle flows controlled by traffic

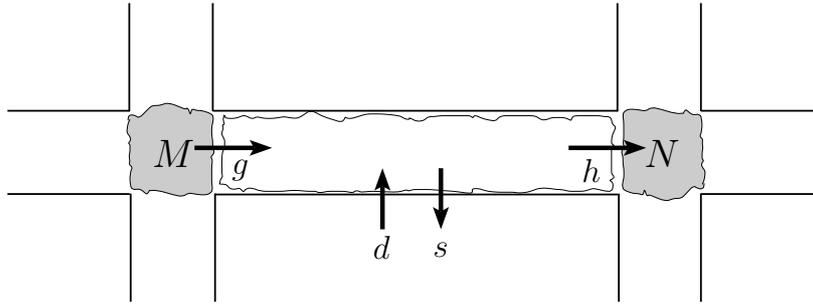


Figure 7: Traffic flows in a link

lights; usually measured in an advanced traffic management system. Contrarily, entering and exiting flows d and s are often non-controllable disturbance terms. Thus, they are able to induce state uncertainty in the traffic modeling and consequently to corrupt the traffic control. Furthermore, the not online measured demand at the boundary of the network (also d) may produce demand uncertainty. Uncertainties caused by d and s may appear for several reasons (parking lots, side-street traffic) in urban road traffic network (see Fig. 8). Hence, uncertainty effects might result in a network per-

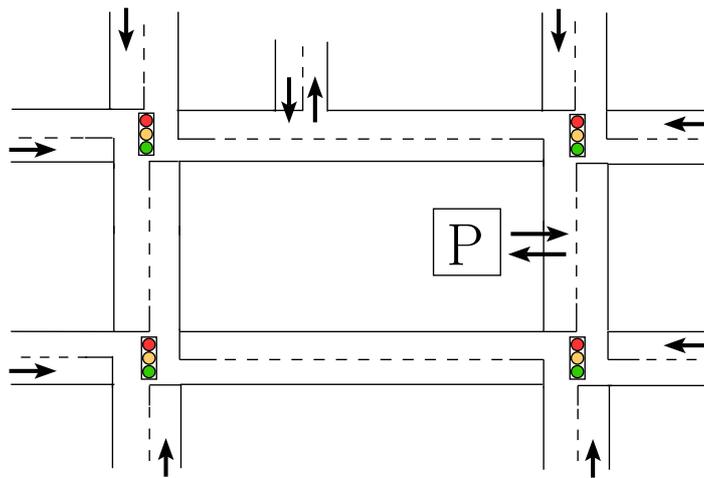


Figure 8: Potential uncertainties (arrows) in urban road traffic network

formance loss in spite of any appropriately designed traffic-responsive control. Moreover, in case of MPC framework [APKK10, dOC10], [TVKB08] the uncertainties (concerning the whole optimization horizon) may further compromise the accurate modeling.

One of the first papers investigating the consequences of uncertain data used for traffic signaling was published by [Hey87]. Furthermore, [Rib94, Yin08, URP10, ZYL10] investigated robust signal calculation methods accounting traffic flow variability. Unlike the aforementioned methods, a different concept is proposed in the thesis, i.e. the store-and-forward traffic model [TVKB08] is augmented by state and demand uncertainty over the predicted time horizon and applied in a model predictive framework. As a traffic control solution, a robust scheme is introduced by using the principle of minimax optimization approach for large-scale urban traffic network:

$$\begin{aligned}
& \min_u \max_{\Delta} \sum_{i=0}^{K-1} x(k+i|k)^T Q x(k+i|k) + u(k+i|k)^T R u(k+i|k), \\
& \text{subject to } u(k+i|k) \in \mathbb{U}, \quad \forall \Delta \in \Delta, \\
& \quad \quad \quad x(k+i|k) \in \mathbb{X}, \quad \forall \Delta \in \Delta, \\
& \quad \quad \quad \Delta(k+i|k) \in \Delta.
\end{aligned} \tag{10}$$

$Q \succ 0$ and $R \succ 0$ are diagonal weighting matrices. Δ represents the set of potential uncertainties. The minimum cost is aimed to be reached under the maximizing effect of uncertainties with appropriately chosen green times $u(k+i|k)$. Optimization (10), however, is NP-hard to be solved directly (the computation time increases exponentially with the network size). Hence, based on the results of [GOL98, Lö03, BV04], the problem is relaxed to an efficiently solvable semidefinite programming (SDP) optimization.

4 Future Works

The planned future research concern the results of Thesis 2 and 4.

The proposed traffic estimation methodology based on the cellular events is a potential candidate for further state-of-the-art ITS applications in urban environment. The method may be applied similarly for arbitrary wireless network with regard to the specifics of the given system, e.g. WI-FI, RFID, Bluetooth. Furthermore, the estimation technique can be further improved through the artificial generation of HO/LAU reports by the operator at given locations within the traffic area. Therefore, the controlled signaling events may contribute to more detailed traffic estimation.

The presented robust signaling method is a centralized traffic control solution. In case of large-scale urban traffic network, this technique can still be adapted by replacing a part of the network (smaller or less important intersections) as uncertainties. Hence, nominal large-scale traffic network can be transformed in a lower scale uncertain network. Furthermore, as an extension of the presented robust method future research work also consists of carrying out a decentralized or distributed traffic control.

References

- [APKK10] K. Aboudolas, M. Papageorgiou, A. Kouvelas, and E. Kosmatopoulos. A rolling-horizon quadratic-programming approach to the signal control problem in large-scale congested urban road networks. *Transportation Research Part C: Emerging Technologies*, 18(5):680–694l, 2010. Applications of Advanced Technologies in Transportation: Selected papers from the 10th AATT Conference.
- [BG08] J. Bokor and P. Gáspár. *Irányítástechnika járműdinamikai alkalmazásokkal*. Typotex, Budapest, 2008.
- [BT97] D.P. Bertsekas and J.N. Tsitsiklis. *Parallel and distributed computation: Numerical methods*. Prentice Hall, Old Tappan, NJ (USA), 1997. ISBN 1-886529-01-9.
- [BV04] S. Boyd and L. Vandenberghe. *Convex optimization*. Cambridge University Press, 2004. ISBN 0 521 83378 7.
- [CDLLR11] F. Calabrese, G. Di Lorenzo, L. Liu, and C. Ratti. Estimating origin-destination flows using mobile phone location data. *Pervasive Computing, IEEE*, 10(4):36–44, 2011.
- [CGW⁺08] J. Candia, M.C. González, P. Wang, T. Schoenharl, G. Madey, and A.-L. Barabási. Uncovering individual and collective human dynamics from mobile phone records. *Journal of Physics A: Mathematical and Theoretical*, 41(22):224015, 2008.
- [CWB08] N. Caceres, J.P. Wideberg, and F.G. Benitez. Review of traffic data estimations extracted from cellular networks. *IET Intelligent Transport Systems*, 2(3):179–192, 2008.

- [dOC10] L.B. de Oliveira and E. Camponogara. Multi-agent model predictive control of signaling split in urban traffic networks. *Transportation Research Part C: Emerging Technologies*, 18(1):120–139, 2010. Information/Communication Technologies and Travel Behaviour; Agents in Traffic and Transportation.
- [GOL98] L. E. Ghaoui, F. Oustry, and H. Lebret. Robust solutions to uncertain semidefinite programs. *SIAM Journal on Optimization*, 9(1):33–52, 1998.
- [GP63] D.C. Gazis and R.B. Potts. The oversaturated intersection. In *Proceedings of the Second International Symposium on Traffic Theory, London, UK*, pages 221–237, 1963.
- [Hey87] B. Heydecker. Uncertainty and variability in traffic signal calculations. *Transportation Research Part B: Methodological*, 21(1):79–85, 1987.
- [Kal60] R.E. Kalman. A new approach to linear filtering and prediction. *Journal of Basic Engineering (ASME)*, 82(D):35–45, 1960.
- [KVB04] B. Kulcsár, I. Varga, and J. Bokor. Constrained split rate estimation by moving horizon. In *16th IFAC World Congress Prague*, volume 16, Czech Republic, 2004.
- [Lö03] J. Löfberg. *Minimax approaches to robust model predictive control*. PhD thesis, Linköping University, Linköping, Sweden, 2003.
- [Mac02] J.M. Maciejowski. *Predictive Control with Constraints*. Prentice Hall, Harlow, UK, 2002.
- [Rib94] P.C.M. Ribeiro. Handling traffic fluctuation with fixed-time plans calculated by TRANSYT. *Traffic Engineering and Control*, 35(6):362–366, 1994.
- [URP10] S.V. Ukkusuri, G. Ramadurai, and G. Patil. A robust transportation signal control problem accounting for traffic dynamics. *Comput. Oper. Res.*, 37:869–879, 2010.

- [Var06] I. Varga. *Közúti folyamatok paramétereinek modell alapú becslése és forgalomfüggő irányítása*. PhD thesis, Budapesti Műszaki és Gazdaságtudományi Egyetem, 2006.
- [VDRW09] D. Valerio, A. D’Alconzo, F. Ricciato, and W. Wiedermann. Exploiting cellular networks for road traffic estimation: A survey and a research roadmap. In *IEEE 69th Vehicular Technology Conference*, pages 1–5. Ieee, 2009.
- [VPW08] G. Vigos, M. Papageorgiou, and Y. Wang. Real-time estimation of vehicle-count within signalized links. *Transportation Research Part C: Emerging Technologies*, 16(1):18 – 35, 2008.
- [Yin08] Y. Yin. Robust optimal traffic signal timing. *Transportation Research Part B: Methodological*, 42:911–924, 2008.
- [ZYL10] L. Zhang, Y. Yin, and Y. Lou. Robust signal timing for arterials under day-to-day demand variations. *Transportation Research Record*, 2192:156–166, 2010.

Publications of the Author

- [LTV11] T. Luspay, T. Tettamanti, and I. Varga. *Forgalomirányítás, Közúti járműforgalom modellezése és irányítása*. Typotex Kiadó, 2011. ISBN 978-963-279-665-9.
- [LTV12] Á. Ludvig, T. Tettamanti, and I. Varga. Travel time estimation in urban road traffic networks based on radio signaling data. In *14th International Conference on Modern Information Technology in the Innovation Processes of Industrial Enterprises, MITIP*, pages 514–527, Budapest, 2012. ISBN 978-963-311-373-8.
- [TDV12] T. Tettamanti, H. Demeter, and I. Varga. Route choice estimation based on cellular signaling data. *Acta Polytechnica Hungarica*, 9(4):207–220, 2012.
- [Tet08] T. Tettamanti. Autópálya forgalmának szabályozása a felhajtó- és változtatható sebességkorlátozás összehangolásával. *Városi Közlekedés*, XLVIII(5):293–296, 2008.

- [TLV08a] T. Tettamanti, T. Luspay, and I. Varga. Forgalomirányító rendszerek zárt hurkú szimulációja. In *MMA Symposium, Innováció és Fenntartható Felszíni Közlekedés Konferencia*, pages 1–8, 2008. CD/IFFK2009Tettamanti-Varga.pdf.
- [TLV08b] T. Tettamanti, T. Luspay, and I. Varga. Összehangolt autópálya-forgalomirányító rendszer vizsgálata zárt hurkú mikroszimulációs környezetben. In *Acta Agraria Kaposváriensis*, volume 12, pages 1–10, 2008. ISSN: 1418-1789.
- [TV09a] T. Tettamanti and I. Varga. Elosztott közúti forgalomirányító rendszer. *Városi Közlekedés*, XLIX(6):338–341, 2009.
- [TV09b] T. Tettamanti and I. Varga. MPC alapú, elosztott városi forgalomirányító rendszer. In *MMA Symposium, Innováció és Fenntartható Felszíni Közlekedés Konferencia*, 2009. CD/IFFK2009Tettamanti-Varga.pdf.
- [TV09c] T. Tettamanti and I. Varga. Traffic control designing using model predictive control in a high congestion traffic area. *Periodica Polytechnica ser. Transp. Eng.*, 37(1-2):3–8, 2009.
- [TV09d] T. Tettamanti and I. Varga. Városi forgalomirányító rendszer prediktív szabályozással. *Városi Közlekedés*, XLIX(3):131–135, 2009.
- [TV10a] T. Tettamanti and I. Varga. Distributed traffic control system based on model predictive control. *Periodica Polytechnica ser. Civil Eng.*, 54(1):3–9, 2010.
- [TV10b] T. Tettamanti and I. Varga. Forgalomnagyság mérése városok közúthálózatán. *Városi Közlekedés*, L(2):99–104, 2010.
- [TV10c] T. Tettamanti and I. Varga. Városi forgalom állapotér alapú modellezése és irányítási módszerei. In *MMA Symposium 2010, Innováció és Fenntartható Felszíni Közlekedés Konferencia*, 2010. ISBN 978-963-88875-0-4.
- [TV11a] T. Tettamanti and I. Varga. Control of road traffic systems - interaction of infrastructure, control system and vehicle. In *INNOMECH 2011, Advanced Control Systems in Vehicles*, pages 37–42, 2011. ISBN 978-963-7294-96-9.

- [TV11b] T. Tettamanti and I. Varga. Robusztus városi forgalomirányítás. *Városi Közlekedés*, LI(1-2):80–84, 2011.
- [TV12a] T. Tettamanti and I. Varga. Development of road traffic control by using integrated VISSIM-MATLAB simulation environment. *Periodica Polytechnica ser. Civil Eng.*, 56:43–49, 2012.
- [TV12b] T. Tettamanti and I. Varga. Urban road traffic estimation based on cellular signaling data. In *14th International Conference on Modern Information Technology in the Innovation Processes of Industrial Enterprises, MITIP*, pages 220–230, Budapest, 2012. ISBN 978-963-311-373-8.
- [TVB07] T. Tettamanti, I. Varga, and J. Bokor. Autópálya forgalomszabályozás felhajtókorlátozás és változtatható sebességkorlátozás összehangolásával és fejlesztési lehetőségei. In *MMA Symposium, Innováció és Fenntartható Felszíni Közlekedés Konferencia*, 2007.
- [TVKB08] T. Tettamanti, I. Varga, B. Kulcsár, and J. Bokor. Model predictive control in urban traffic network management. In *16th Mediterranean Conference on Control and Automation*, pages 1538–1543, Ajaccio, Corsica, France, 2008. CD ISBN: 978-1-4244-2505-1.
- [TVP10] T. Tettamanti, I. Varga, and T. Péni. *Model Predictive Control*, chapter MPC in urban traffic management, pages 251–268. InTech, 2010. ISBN 978-953-307-102-2.
- [TVP⁺11] T. Tettamanti, I. Varga, T. Péni, T. Luspay, and B. Kulcsár. Uncertainty modeling and robust control in urban traffic. In *18th IFAC World Congress*, pages 14910–14915, 2011.
- [VKLT08] I. Varga, B. Kulcsár, T. Luspay, and T. Tettamanti. Korszerű szabályozások a közúti forgalomirányításban. *A Jövő Járműve*, 1-2:34–36, 2008.