Model based estimation and control of road traffic flow parameters

Overview of Ph.D. Thesis

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1 The motivation and method of research

One of the major challenges in transport science is designing traffic systems brought about in crowded environments, and the running of the same. This is especially true of road traffic, more precisely, of traffic networks. In the majority of cases, the further expansion of the pathway, in the interest of meeting the increasing requirements, is not possible, therefore, a better exploitation of the present network must be the aim. In this endeavour an effective control of traffic processes is indispensable, with up-to-date road traffic control, as a new approach. Integrating theoretical results from other disciplines, and raising the technical level of control devices can help in solving control problems.

In course of research my aim was to explore a part of control problems in road traffic and to provide solutions regarding the same by help of modern control theory. The motivation is based on the perception that, due to the peculiarities of road traffic, satisfactory, qualitative solutions may be based only on modern robust control algorithms.

One of the features of road traffic is that very often not all the measurement data of processes are available for the control process. The control of systems of this kind is possible only by estimating the inner state of the system and by designing robust control, in course of which different disturbances, as well as errors in modelling, furthermore, uncertainties can be taken into consideration.

In my research I came to another general conclusion. In the control of road traffic the strong restrains regarding the road processes and control signal imply an essential problem. For these equality and inequality constraints I had to find methods which allow estimating and controlling the state of road processes under constraints. The significance of the task I have completed in course of my research is in the state-estimation and control under the above constraints and its elaboration regarding traffic control systems. With these techniques I have succeeded in demonstrating qualitative improvement in simulation, with respect to other state-space-based estimation and control algorithms.

2 Research objectives and history

Science of engineering has gone through considerable change these days, in course of which the application of information devices gets wider in a large scale. A prominent field developing rapidly is signal and systems theory, system analysis and as a consequence, control engineering. In course of the design of control systems, from the 60-s, the classical methods of analysis and synthesis (Bode, Nichols, Nyquist) were supplemented with in time domain methods of systems- and control theory. These modern trends were characterized by the introduction of system-state and state-space, thus, the designing methods related to them were named state-space methods. One of the most outstanding representatives of this epoch is Rudolf Kálmán, born in Hungary, whose publications [11],[12] in the 60-s served as the elaboration of several basic concepts and as solutions of numerous problems. State-space theory is a major element of systems- and control theory, furthermore, of the design of up-to-date control systems in our days (postmodern).

The first attempts in mapping road traffic flow processes in state-space started 30 years ago. The basic idea of estimating the state of processes on roads traffic shaped, first, in the publications of Nahi and Trivedi [20]. In the 80-s Cremer and Keller [5],[6], furthermore, Nihan and Davis [21],[22] estimated Origin-Destination (OD) traffic processes in simple crossings. Besides state-estimations, the design of dynamic state-feedback-based controls in public road systems gained an increasing significance [23]. In the frame of one of the major projects, Papageorgiu et all started ALINEA control [24] on the beltway around Paris, which was followed by solutions based mainly on optimal LQ control [25]. In Hungary the state space approach has not been spread yet. In the general traffic control field Gilicze, Fi and Maklári brought new results.

2.1 Estimation of Origin-Destination matrix with constraint moving horizon

Information related to the direction of vehicles in a traffic system is regarded a parameter characteristic to traffic. The connection between the input flow and output flow of vehicles is based on the „where to-where from” information, which can be arranged in a matrix [6],[5]. The structure referred to as *célforgalmi* matrix in the Hungarian terminology, can be defined regarding an entire urban network or a simple intersection only. The parameters of highway traffic, thus, the data of origin destination (OD) cannot be measured by automatic devices, still we are able to estimate them by applying a state observer [4],[31],[32]. Kalman-filter works in this relation, but does not always provide exact value, due to restrains characteristic to the processes. The fact according to which for estimating the *célforgalmi* matrix, some kind of state observer, suitable also for considering restrains, is advisable to be used, is based on the above perception. From among the technicalities available, the application of Moving Horizon Estimation with constraint [2],[26],[27] seemed to be the most promising one.

2.2 Local intersection controller with Congestion Detection Filter

The primary aim of local intersection controller is to state the priority conditions at the intersections, furthermore, to ensure safe passing so that traffic flow should be the smoothest possible. Attributes for estimation: passing time, the number of the vehicles waiting at the stop line, number of halts, environmental loads and other quality indices. One of the major problems of the control system running in a crowded environment is that the impact of the control cannot always get across, since in the overcrowded traffic, vehicle motion is hold up by jams. This is intensified by the fact that, generally, the local intersection controller devices are suitable for subjected to only one objective function, therefore, the need for a reconfigurable controller structure arises.

The aim in my research was to elaborate a control structure, in which there is a possibility to modify the traffic light depending on the congestion information. The number of congested vehicles could be estimated with a fault detection filter. During my research I found that the FPRG filter [19],[15] suited for this assignment.

2.3 Road traffic network controlling with Model Predictive Controller

In case the distance is relatively short between several intersections with traffic lights, it is advisable to co-ordinate the operation of the intersection controller devices [13],[17]. The co-ordination may include public transport devices and pedestrian traffic, too, besides vehicles. Where several intersections are near to each other in smaller or bigger networks, primarily in cities, the co-ordination is especially emphasized.

The aim of my research was to elaborate a control process related to networks consisting of several junctions, which perform the control of all the traffic lights in its sphere of action in a co-ordinated way, depending on the traffic. The controller must be able to dynamically make the traffic signal set of the intersections. From the point of view of realization, this means that before every period, a new traffic sign must be generated regarding all the traffic lights, in harmony with the present traffic. To solve the above, one must choose a method in which it is possible to take all the constraints into consideration, in course of the set of control input. For the above, the procedure based on model predictive controller [18],[10] is suitable, in which the minimization of the number of the vehicles waiting at the stop line can be the aim.

2.4 Traffic flow mapping as a positive systems

Positivity of the variables often emerges as the immediate consequence of the nature of the phenomenon itself [8]. A huge number of evidences are just before our eyes: any variable representing any possible type of resource measured by a quantity. As stated in Professor Luenberger's book on dynamic systems, *a positive system is a system in which the state variables are always positive (or at least nonnegative) in value*.

The state variables and parameters of road traffic systems also have positive features, the values of the state variable - based on their original physical meaning (naturally positive) – are always positive (e.g. traffic flow, number of vehicles, traffic density). Moreover the control inputs are also positive.

In my research it became obvious that the positive linear systems have strict conditions (terms) of controllability [1],[28],[29],[30] and modelling, so it is reasonable to treat naturally positive systems as general linear systems and control them in the positive orthans with controllers.

2.5 The verification of the applied model

When building a process model for control purposes, one must try to obtain a minimal representation model. These are simplified models, they are not suitable for the exact simulation of processes, but they are perfectly adequate for designing model based estimators and control systems, especially if the plants can be described with linear models. The errors resulting from model simplification can be handled using robust control techniques.

The models used in my thesis belong to the "Store and forward" family, more exactly they resemble most the TUC model type. The TUC models are justified in many publications and also proved to perform well in dynamic traffic control systems in case of three big cities: Chania, Greece, 23 intersections; Southampton, UK, 53 intersections; Munich, Germany, 25 intersections [14].

3 New scientific achievements (thesis)

1. Thesis. *I elaborated a model-based method for vehicular traffic processes state variables and parameters estimation with constraints. The method was demonstrated through the estimation of an OD matrix where the state variables are the elements of the matrix.*

- I analysed the current methods used for the estimation of hardly or not at all measurable traffic flow parameters. I pointed out the shortcomings of existing Kalman-filter based solutions. The expected value estimated with Kalman-filter is not always appropriate, due to the constraining conditions extant on the flow (process) states. I demonstrated that, with the cMHE technique, the estimation of the target traffic matrix can be done also when constraints are to be applied, this way reducing the estimation errors (its expected value, in the case of stochastic models).
- The LTI model is given by:

$$x_{ij}(k+1) = x_{ij}(k) + w_{ij}(k), \tag{3.1}$$

  where $w_{ij}(k)$ is the state noise, $x_{ij}(k)$ is the split rate or turning rate that shows the percentage of vehicles coming from direction i that turned and exited direction j, k=1,2,…..N. In the system the entering and leaving vehicle number is measured, the measuring equation being given by:

$$y_j(k) = \sum_{i=1}^{n} q_i(k) x_{ij}(k) + v_j(k), \tag{3.2}$$

  where $q_i(k)$ represents the traffic volume (the number of vehicles) entering the intersection from entrance i, during k time interval, $y_j(k)$ traffic volume (the number of vehicles) leaving the intersection from exit j, i = 1,...,n and j = 1,...,m, $v_j(k)$ is a zero mean noise term. The input measurement is a noisy term where $\zeta_i(k)$ is a zero mean noise term.
- I showed that the system states are estimable even with the consideration of the constraints below:

$$\begin{gathered} 0 \le x_{ij}(k) \le 1 \\ \sum_{j=1}^{m} x_{ij}(k) = 1 \end{gathered} \tag{3.3}$$

- For the design of the constrained state observing I proposed the constrained Moving Horizon Estimation (MHE) technique. The technique estimates the expected states values in order that the Ψ_k functional is minimized while subjected to the dynamic equation (3.1) as the measurement equation (3.2).

$$\min_{(\bar{x}_{k-N-1},\hat{w}_{k-N-1|k},\ldots,\hat{w}_{k-1|k})} \Psi_k$$

$$\Psi_k = \hat{w}^T_{k-N-1|k} Q_0^{-1} \hat{w}_{k-N-1|k} + \sum_{j=k-N}^{k-1} \hat{w}^T_{j|k} Q^{-1} \hat{w}_{j|k} + \sum_{j=k-N}^{k} \hat{v}^T_{j|k} R^{-1} \hat{v}_{j|k} + \Psi^*_{k-N} \tag{3.4}$$

The dynamic equations:

$$\hat{x}_{j+1|k} = A\hat{x}_{j|k} + G\hat{w}_{j|k} \quad j = k-N-1,\ldots,k-1 \tag{3.5}$$

$$y_j = C\hat{x}_{j|k} + \hat{v}_{j|k} \quad j = k-N-1,\ldots,k \tag{3.6}$$

The initial value:

$$\hat{x}_{k-N|k} = \bar{x}_{k-N} + \hat{w}_{k-N-1|k} \tag{3.7}$$

The thesis is based on the work presented in chapter 3 and on the [V-1],[V-5], [V-6],[V-9],[V-10],[V-11] publications, respectively.

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2. Thesis. *I elaborated a method for local intersections' traffic light control where the number of congested vehicles was estimated with the fault detection filter. Further, I used the congestion information obtained in the structure of the reconfigurable controller of the traffic light, the base of which is given by the LQ control algorithm.*

- I analysed the current methods of local intersections' traffic light controllers, furthermore, I developed a proposal for the dynamic description of vehicles movement in the state space in the following LTI model:

  $$x(k+1) = Ax(k) + Bu(k) + x_{be}(k) + v_q(k) + x_f(k) \tag{3.8}$$

  The measurement equation:

  $$y(k) = Cx(k) + v_y(k), \tag{3.9}$$

  where $x(k)$ is the state vector, representing the number of vehicles standing in a certain branch of the intersection. The control input is the green time $u(k)$. The B matrix elements represent the saturation flow. In the system the $x(k)$ and the entering flow $x_{be}(k)$ are measured. The v_q and the v_y are measurement noises (zero mean random components).

- I showed that in model (3.8) the detection of the number of vehicles $x_f(k)$ not able to leave the intersection is possible, which represents the calculation of the (3.10) state's equation residual information. For the determination of (residual) congestion information I designed the FPRG fault detection filter. The discrete LTI model is given by

$$z(k+1) = Fz(k) - Ey(k) + \overline{D}u(k)$$
$$r(k) = Mz(k) - Hy(k) \qquad (3.10)$$

where r is the residual, z is the state of the filter, while F, E, D, M, H parameter matrices are the corresponding discrete matrices of the system's continuous FPRG error detection filter matrices.

- With the Congestion Detection Filter the degree of congestion in the entering ramification can be determined, which I further used in the traffic light control. I developed a reconfigurable, optimal controller structure, which regenerates the traffic signal set at the beginning of every cycle. The base of the controller's algorithm is an LQ optimal controller that, based on the estimated congestion, is able to reconfigure the control.

The thesis is based on the work presented in chapter 4 and on the [V-7],[V-13],[V-14],[V-31] publications, respectively.

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3. Thesis. *I elaborated a method for multiple ramification roads traffic light networks' control. I showed that by employing the predictive control model, the dynamic determination, per cycle, of the design of the traffic light's period is possible even with the consideration of the natural constraints existing in the system.*

- I analysed the current methods used for traffic control of multiple ramifications traffic lights networks. Furthermore I elaborated a proposal for vehicles movement inscription in the state space based on the TUC [7] model. In the case of multiple ramifications traffic lights networks for the portrayal of vehicles movement in the space state I proposed the following discrete time stochastic LTI state equation:

$$x(k+1) = Ax(k) + Bu(k) + x_{be}(k) + w(k), \qquad (3.11)$$

where $x(k)$ is the state vector, representing the number of vehicles standing in a certain branch of the intersection. The control input is the green time $u(k)$, x_{be} is the number of input vehicles (which I considered as the measurable fault/noise), w is the sum of the non-measurable faults/noise, while v is the measurement noise (zero mean random components):

$$y(k) = Cx(k) + v(k) \qquad (3.12)$$

- I formulated a method for the conformation of matrix B in a multiple ramifications network, and showed that satisfying the following constraints on the control input is possible:

$$u_i \geq t_{MIN} \qquad \forall \mathrm{i} \tag{3.13}$$

$$u_i \leq t_{MAX} \qquad \forall \mathrm{i} \tag{3.14}$$

$$\sum_{i=1}^{O_j} u_i \leq t_j^{MAX} \qquad j = 1 \ldots J \,, \tag{3.15}$$

where O_j is the number of vehicles' columns in the intersection j, J is the number of controlled intersections.

- I elaborated a method for designing an MPC controller, which minimizes the number of vehicles in queue. The controller establishes the control input in order to minimize the next functional while satisfying the dynamic equation (3.11), the measurement equations (3.12) and the (3.13), (3.14), (3.15) constraints:

$$J(k) = \frac{1}{2} \sum_{i=1}^{N_p} \left(x_i^T(k) Q x_i(k) + u_i^T(k) R u_i(k) \right) \tag{3.16}$$

where N_p is the length of the predictive horizon, $x_i(k)$ is the state vector, representing the number of vehicles standing in a certain branch of the intersection, $u_i(k)$ is the control input (green time).

The thesis is based on the work presented in chapter 5 and on the [V-7],[V-2], [V-3],[V-4] publications, respectively.

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4. Thesis. *I developed a method in which the traffic flows are modelled as a general (not positive) linear system. The positive characteristic in the feedback loop was taken into consideration when designing the controller by incorporating the appropriate constraints. I elaborated a proposal for determining the design conditions of the controller that makes it possible to control the traffic flow modelled as a linear system in the positive orthans.*

- I pointed out that the traffic flows analysed are naturally positive, in other words, the states are positive, and furthermore, even the control signal is positive. A consequence of the positive characteristic is that the physically sensible solutions (trajectories) of the state space models contain only non-negative coordinates. The control task is being made more difficult by the fact that constraining conditions are applying to the control input.

- I showed that due to the modelling and controlling problems of positive linear systems the model-class mapped as general linear system, but controlled only inside the positive orthans, seems to be the most promising for solving practical tasks.

- I made proposals for the application of methods and constraining techniques needed for the controller design, in which considering the positive characteristics of states and control inputs is possible. In the case of using the predictive model controller algorithm I made a proposal for the selection of the dimension of the predictive horizon.

The thesis is based on the work presented in chapter 6 and on the [V-2], [V-30] publications, respectively.

4 Further research and practical applications

The results show clearly that further research should be on the basis of integrating features. In the case of urban networks with several coordinated intersections, one of the principle parameters of the method is the turning rates which were considered to be constant. In real operation with changing traffic conditions these parameters may vary naturally, consequently, in order to get the most proper and accurate performance, one could use the results of estimating these rates as it was stated in my first thesis. Moreover, the synthesis of the congestion detection filter developed in the second thesis with this estimation based control structure would increase the efficiency of the system. Another possible way of improvement is to replace queue length by total travel time in the cost function. However, the use of this variable infers a completely new non-linear network model.

These methods could be applied in everyday use if traffic control machines had the capability of solving complex programming problems like this. As result of the technological developments of past few years, modern machines are able to perform operations like this, consequently my methods could be tested soon in the future. I am convinced that one of the most promising implementations should be the origin-destination matrix estimation which would be useful especially in roundabout traffic systems.

5 References

[1] Bacciotti, A.: On the positive orthant controllability of two-dimensional bilinear systems, Sys. Control Lett., 3: 53-55, 1983

[2] Bemporad, A., Mignone, D., Morari, M.: "Moving Horizon Estimation for Hybrid Systems and Fault Detection" ACC San Diego, California, 1999

[3] Bokor J.: LQ control. BME KAUT doktori képzés segédlet. 2006

[4] Cremer, M., Keller, H.: "Dynamic Identification of Flows from Traffic Counts at Complex Intersections" Proc. 8th Int. Symposium on Transportation and Traffic Theory, University of Toronto Press, Toronto Canada, 1981, pp 199-209.

[5] Cremer, M., Keller, H.: "Systems Dynamics Approach to the Estimation of Entry and Exit O-D Flows" Ninth International Symposium on Transportation and Traffic Theory, VNU, Utreccht, The Nederlands, 1984, pp. 431-450.

[6] Cremer, M., Keller, H.: "A New Class of Dynamic Methods for the Identification of Origin-Destination Flows" Transportation Research-B, 1987, Vol. 21B, No. 2, pp. 117-132.

[7] Diakaki, C, Dinopoulou, V., Aboudolas, K., Papageorgiou, M., Ben-Shabat, E., Seider E., and Leibov, A.: Extensions and new applications of the Traffic Control Strategy TUC. TRB 2003 Annual Meeting, 2003.

[8] Farina, L., Rinaldi, S.: Positive linear systems: Theory and applications. New York: Wiley, 2000.

[9] Hangos, K., Bokor, J., Szederkényi, G.: Computer controlled systems. Veszprémi Egyetemi Kiadó. 2002. ISBN 963 9220 94 9

[10] Hegyi, A.: Model Predictive Control for Integrating Traffic Control Measures. PhD Thesis Technische Universiteit Delft, 2004

[11] Kalman, R.E.: "A New Approach to Linear Filtering and Prediction" Journal of Basic Engineering (ASME), 1960, 82D, pp. 35-45.

[12] Kalman, R.E., Ho, Y.C., Narendre, K.S.: Controllability of Dynamic Systems, Contribution to Differential Equations, Vol. 1. Pp. 189-213.

[13] Kövesné dr. Gilicze Éva: Összehangolt, időterv szerint működő jelzőlámpás kereszteződések forgalmi folyamatai. Kandidátusi értekezés, MTA 1977

[14] Kosmatopoulos, E., Morris, R., Bielefeldt, C., Richards, A., Mueck, J., Weichenmeier, F., Papageorgiou, M.: Field evaluation of the signal control strategy TUC at three urban traffic networks. Pprints 4th IFAC Workshop,

Bansko, Bulgaria, 3-5 October 2004, pp. 67-73.

[15] Kulcsár, B.: Design of robust detection filter and fault correction controller. PhD doktori értekezés. 2005

[16] Luenberger, D.: Introduction to Dynamics Systems, Wiley, New York, 1979

[17] Nagy Ervin – Szabó Dezső (szerk.): Városi közlekedési kézikönyv – Műszaki Könyvkiadó, Budapest, 1984

[18] Maciejowski, J. M.: Predictive Control with Constraints. Prentice Hall. 2002

[19] Massoumnia, M. A.: A geometric approach to the synthesis of failure detection filters. IEEE Transactions on Automotic Control, AC-31(9):839–846, 1986

[20] Nahi, N., Trivedi, A.: Recursive Estimation of Traffic Variables: Section Density and Average Speed, Transportation Science, Vol 7, pp 269-286., 1973

[21] Nihan, N.L. and Davis, G.A.: "Recursive Estimation of Origin-Destination Matrices from Input/Output Counts" Transportation Research B, 1987, Vol. 21B, No. 2, pp. 149-163.

[22] Nihan, N.L. and Davis, G.A.: "Application of Prediction-Error Minimization and Maximum Likelihood to Estimate Intersection O-D Matrices from Traffic Counts" Transportation Science, 1989,Vol 23, No 2.

[23] Papageorgiou, M.: „Applications of Automatic control concepts to Traffic Flow Modeling and Control” Lecture Notes in Control and Information Sciences 50. Springer-Verlag, 1983

[24] Papageorgiou, M., Haj-Salem, H., & Blosseville, J.: ALINEA: a local feedback control law for ramp metering. Transportation Research Record, 1320, pp. 58-64., 1991

[25] Papageorgiou, M. "Concise Encyclopedia of Traffic and Transportation Systems" Pergamon Press, 1991

[26] Rao,V. C. "Moving Horizon strategies for the constrained Monitoring and Control of Nonlinear Discrete-Time Systems" PhD Thesis U. of Wisconsin-Maidson, 2000

[27] Rao,V. C., Rawlings, J. B., Mayne, D. Q.: "Constrained State Estimation for Nonlinear Discrete-Time Systems: Stability and Moving Horizon Approximations" IEEE Transaction on Automatic Control, 2003, Vol 48. pp. 246-258.

[28] Sachkov, Y. L.: Controllability of bilinear systems with a scalar control in the positive orthant, (in Russian) Mat. Zametki 58 (1995), no. 3, 419-424;

translation in Math. Notes 58 (1995), no. 3-4, 966-969 (1996).

[29] Sachkov, Y. L.: On positive orthant controllability of bilinear systems in small codimensions, SIAM J. Control Opt., 35: 29-35, 1997

[30] Valcher, M.E.: Controllability and reachability criteria for discrete-time positive systems, International Journal of Control 65(3) (1996) 511-536.

[31] Zijpp, N.J. van der: "Dynamic origin-destination matrix estimation from traffic counts and automated vehicle identification data" Transportation Research Record No. 1607. TRB, Washington, DC, 1997, pp. 87-94.

[32] Zijpp, N.J. van der: "Comparison of methods for dynamic origin-destination matrix estimation" IFAC Transportation Systems Symposium, Chania, Grecce, 1997, pp. 1445-1450.

6 The author's publications

6.1 Publications related to the dissertation

6.1.1 Foreign language journals

[V-1] Kulcsár, B., Bécsi, T., Varga, I.: Estimation of dynamic origin destination matrix of traffic systems, Periodica Polytechnica ser. Transp. Eng., Budapest, Hungary, 2004, Vol. 33. No 1-2. pp. 3-14.

[V-2] Varga, I., Bokor, J.: New Approach in Urban Traffic Control Systems, Periodica Polytechnica ser. Transp. Eng., Budapest, Hungary, (accepted)

[V-3] Péni, T, Varga, I., Szederkényi, G. and Bokor, J.: Robust model predictive control with state estimation for the pressurizer system of the Paks nuclear power plant. Hungarian Journal of Industrial Chemistry Veszprém, 2005, Vol. 33(1-2) pp. 89-96.

[V-4] Varga, I., Kulcsár, B., Péter, T.: Design of intelligent traffic control system. ERCIM NEWS NO. 64, pp. 38-39, April 2006

6.1.2 Hungarian language journals

[V-5] Kulcsár Balázs, Varga István, Bokor József: Modern közúti forgalomirányítás I., A forgalmi paraméterek becslése. Városi Közlekedés 2005/1 pp. 23-26.

[V-6] Varga István, Kulcsár Balázs, Bokor József: „Automatikus eseménydetektálás állapot-megfigyelővel" Közlekedéstudományi Szemle LVI. évfolyam 6. szám, (2006. június) pp. 208-214.

[V-7] Varga István, Kulcsár Balázs, Bokor József: Modern közúti forgalomirányítás II., Jelzőlámpás szabályozás. Városi Közlekedés 2006/3 pp. 161-165.

6.1.3 International conferences

[V-8] P. Gáspár, I. Szászi, T. Bartha, I. Varga, J. Bokor, L. Palkovics and L. Gianone: „Visual lane and obstruction detection system for commercial vehicles," in Proceeding. of the SafeProcess '2000 Conference, vol. 2, pp. 908-913, Hungary, June 2000.

[V-9] István Varga, Balázs Kulcsár, József Bokor: General Moving Horizon Estimation of Traffic Systems. The 12th Mediterranean Conference on Control and Automation. Kusadasi, Aydin, Turkey, June 6- 9, 2004. „\pdfs\med_pdfs\1125.pdf"

[V-10] Balázs Kulcsár, István Varga: Simulation Of Turning Rates In Traffic Systems. The 16TH EUROPEAN SIMULATION Symposium (ESS2004). Budapest, Hungary, October 17-20, 2004, ISBN: 1-56555-286-5 (book), pp. 291-296; ISBN: 1-84233-106-X (CD) „\pdf\log-39.pdf"

[V-11] Kulcsár, B., Varga, I., Bokor, J.: „Constrained Split Rate Estimation by Moving Horizon" 16th IFAC World Congress Prague, Czech Republic, July 3-8, 2005, IFAC2005 DVD „\Fullpapers\03276.pdf "

[V-12] Tamás Luspay, István Varga, Balázs Kulcsár: Modeling and parameter estimation in road traffic systems. MITIP September 11-12, 2006, Budapest pp.415-420.

[V-13] Varga, I.: Connection between modern traffic management systems. Proceedings of the Symposium on euroconform complex retraining of specialists in road transport, (Budapest), pp. 333-338, Budapest University of Technology and Economics, Hungary, 9-15 June 2001

[V-14] István Varga, Balázs Kulcsár, József Bokor: Traffic Light Control Using Moving Horizon Estimation. 9th MINI Conference on Vehicle System Dynamics, Identification and Anomalies (VSDIA 2004) pp. 453-464, Budapest, Hungary 8-10. November, 2004

[V-15] Kulcsár, B., Varga, I., Bokor, J.: Estimation of road traffic parameters. In: Workshop on system identification and control systems. Budapest. Hungary 11. July, 2005

6.1.4 Conferences in Hungary

[V-16] Varga I.: Korszerű forgalomirányító rendszerek. TEMPUS JEP-14191-99 "Euroconform Complex Retraining of Specialists in Road Transport" kurzus keretében, Miskolc, 2001. szeptember 21.

[V-17] Varga I.: „Korszerű forgalomirányító központok", az „Automatizált forgalomszámláló és kiértékelő rendszerek", és a „Közúti forgalomirányító berendezések" című előadások a TEMPUS JEP-14191-99 kurzus keretében, Győr, 2001. október 1.

6.1.5 Electronic publications (Hungarian)

[V-18] Varga I., Katkó L., Molnár G., „Forgalomirányító Központok" BME Közlekedésautomatikai Tanszék, 1998. Segédlet. http://www.kka.bme.hu/~kozut/

[V-19] Katkó L., Varga I., Molnár G., „Közúti forgalomirányító berendezések" BME Közlekedésautomatikai Tanszék, 1999. Segédlet. http://www.kka.bme.hu/~kozut/

[V-20] Katkó L., Molnár G., Varga I., „Kombinált közúti-vasúti forgalomirányító rendszerek” BME Közlekedésautomatikai Tanszék, 1999. Segédlet. http://www.kka.bme.hu/~kozut/

[V-21] Katkó L., Varga I., Molnár G., „A közúti közlekedési forgalom mérésének módszerei és technikai eszközei” BME Közlekedésautomatikai Tanszék, 2000. Segédlet. http://www.kka.bme.hu/~kozut/

[V-22] Varga István, Kulcsár Balázs, „Forgalmi paraméterek mérése és becslése” BME Közlekedésautomatikai Tanszék, 2006. Segédlet. http://www.kka.bme.hu/~kozut/

6.1.6 Technical report

[V-23] Tóth János, Varga István: „A korszerű közlekedési forgalomirányító rendszerek.” TEMPUS JEP-14191-99 keretében (3.2 fejezet) 2001. (26 oldal)

[V-24] Varga István: A közúti közlekedés forgalmi paramétereinek a mérése, a mérés helyettesítése becsléssel (1.1-K1-2) EJJT RET Kutatási jelentés 2005 (30 oldal)

[V-25] Varga István, Kulcsár Balázs: A becslési módszerek alkalmazhatósága a közúti közlekedésben. (1.1-K1-3) EJJT RET Kutatási jelentés 2005 (21 oldal)

[V-26] Bécsi Tamás, Varga István: A közúti közlekedésben előforduló anomáliák kiszűrése, incidensek detektálása. (1.1-K2-4) EJJT RET Kutatási jelentés 2005 (27 oldal)

[V-27] Kulcsár Balázs, Varga István: A közúti közlekedési modellek paramétereinek vizsgálata a szabályozás szempontjából. Érzékenység vizsgálatok (1.1-K4-2) EJJT RET Kutatási jelentés 2005 (16 oldal)

[V-28] Varga István: A közúti közlekedésben jelenleg használt forgalomirányítási módszerek (1.1-K4-3) EJJT RET Kutatási jelentés 2005 (30 oldal)

[V-29] Varga István, Kulcsár Balázs: A közúti forgalomirányításban jelenleg használt beavatkozó eszközök, és a modern forgalombefolyásoló rendszerek. (1.1-K4-4) EJJT RET Kutatási jelentés 2005 (17 oldal)

[V-30] Matolcsi Máté, Varga István: Pozitív bilineáris rendszerek irányíthatósága. MTA SZTAKI 2006/5 (13 oldal)

[V-31] Varga István, Kulcsár Balázs, Preitl Zsuzsa: Egyedi jelzőlámpás csomópont forgalomfüggő szabályozási lehetősége új módszerek segítségével. (1.1-K3-1) EJJT RET Kutatási jelentés 2006 (17 oldal)

6.2 Publications not directly related to the dissertation

6.2.1 Foreign language journals

[V-32] István Varga, Tamás Bartha, Alexandros Soumelidis: On-line Testing of the Reactor Protection System in the Paks Nuclear Power Plant. ERCIM NEWS NO. 56, pp. 33-34, Januar 2004

6.2.2 International conferences

[V-33] Varga, I. and Katics, B.: Testing concept for proper functioning of the reactor protecting system in the nuclear power plant of Paks. Proceedings of the 13th International DAAAM Symposium. (Vienna) pp. 587-588, Austria, 2002.

[V-34] István Varga, Tamás Bartha, Alexandros Soumelidis, Béla Katics: A concept for on-line testing of distributed safety-critical supervisory systems. IMS 2003 7th IFAC Workshop on Intelligent Manufacturing Systems (Budapest) pp. 175-180, Hungary, 6-8 April 2003

[V-35] István Varga, Tamás Bartha, Géza Szabó, Bálint Kiss: Status and Actual Risk Monitoring in a NPP Reactor Protection System. 7TH International Conference On PSAM, Berlin 2004. pp. 2654-2659.

[V-36] T. Bartha, I. Varga, A. Soumelidis, G. Szabó: „Implementation of a Testing and Diagnostic Concept for an NPP Reactor Protection System", 5th European Dependable Computing Conference (EDCC-5), Springer-Verlag GmbH, ISBN: 3-540-25723-3, pp. 391.

[V-37] I. Varga, G. Szederkényi, K. M. Hangos And J. Bokor: Modelling and model identification of a pressurizer at the Paks Nuclear Power Plant. In 14th IFAC Symposium on System Identification, pp. 678 – 683, 2006. CD\ID060210.pdf

6.2.3 Conferences in Hungary

[V-38] Szabó Géza, Varga István, Bartha Tamás: Állapotmonitorozási és megbízhatósági információk integrálása erőművi informatikai rendszerekben. Acta Agraria Kaposvárinesis. Volume8 No3 2004 ISSN 1418-1789, pp. 99-115

[V-39] Bokor József, Bartha Tamás, Varga István: „Biztonsági kockázatok az irányítástechnikai architektúrában", Szerkezetek élettartam gazdálkodása konferencia, MTA PAB – PA Rt, Pécs 2005. november 9.-11. CD- kiadvány (megjelenés alatt)