Institute of Information and Communication Technologies – Bulgarian Academy of Sciences

Modelling and optimization of urban traffic in network of crossroads

Project KP06-H37/6
Funded by the Bulgarian Research Fund

Institute of Information and Communication Technologies – Bulgarian Academy of Sciences

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BULGARIAN SCIENCE FUND

Work programme

Work package 1: **Analysis of formal models applied for traffic control**

Work package 2: **Research of optimal control in transportation systems by hierarchically determined optimization problems**

Work package 3: **Numerical experiments and simulations for validation of the determined hierarchical optimization problem, the used approach and the appropriate algorithms**

Work package 4: **Dissemination of scientific results**

Work package 5: **Project management**

The goal of the research →

Synthesis of new models for optimal control of urban traffic network in order to improve the traffic behavior.

Intelligent methods for urban traffic control - minimization of vehicle queue lengths in front of the junctions in urban network,

which leads to
faster driving,
better ecological picture,
reducing the air and noise pollution,
economical and social consequences.

Traffic control and applied methodology

For the traffic lights control it is possible to apply four types of control influences:

- **the traffic lights *split* (green light duration),**
- **traffic light *cycle* duration**
- **the *offset,* allowing a “green wave” of the traffic**
- ***stage specification* (priorities of chosen directions)**

The available models apply only one type of the control variables

This research develops models, which integrate a set of two control variables: split and cycle durations, which benefit the control process by increase of the control space of the traffic lights control

II. TRAFFIC CONTROL MODELING

Two general methodologies for modelling the traffic control:

- the first is based on the continuity of flows and the analogy between the liquid and traffic flow dynamics.

- The "Store-and-forward-modelling" (simple model)

$$x = x^0 + x^{in} - su \qquad (1)$$

The cycle duration is not presented explicitly in (1). In this research the cycle duration *y*, will be introduced in an optimization problem, applying hierarchical approach.

III. TRAFFIC CONTROL OBJECT

The urban network, under consideration is an intensive area in Sofia between “Shipchenski prohod” blvd and “Geo Milev”, Fig. 1.

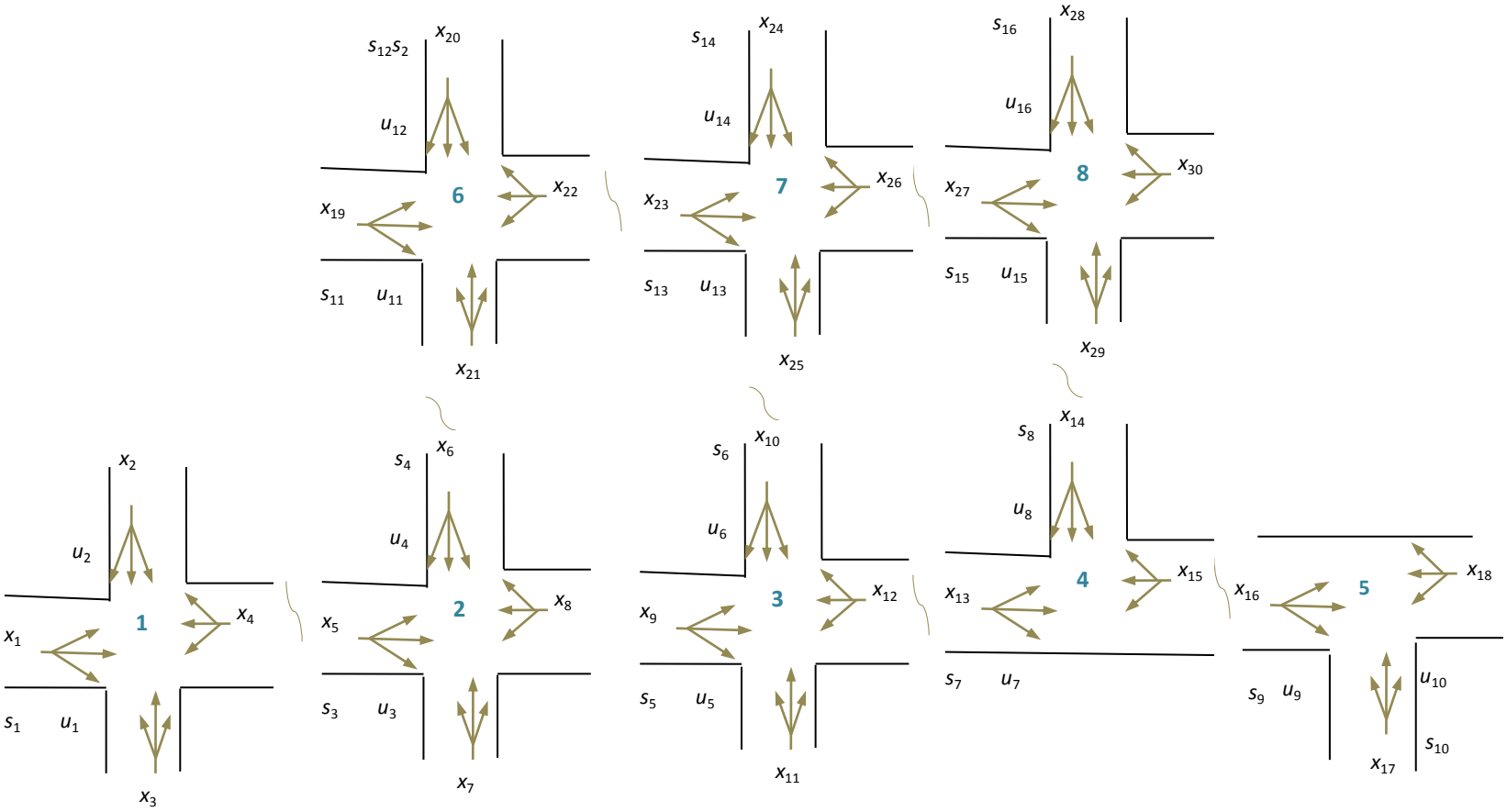


Fig.1 Urban traffic network

III. BI-LEVEL FORMALIZATION OF THE TRAFFIC CONTROL

The advantages of the bi-level optimization are the possibilities to formalize the coordination of the traffic junctions and the interactions among them by the traffic flows

The goal function of the low-level problem is chosen to minimize all 30 queue lengths x_i, i=1,…30 of the eight junctions by changing the splits of the green lights - 16 control variables, u_j, j=1,…,16.

$$\min_{\substack{i=1,\dots,30 \\ j=1,\dots,16}} \left(x_i^2 + u_j^2\right) \qquad (2)$$

$$A_1 x + A_2 u \leq B$$

The constraints for the first junction are:

$$x_1 + (1 + l_1 + l_2) s_1 u_1 \leq x_{1_o} + x_{1_{in}} \quad x_2 + (1 + l_1 + l_2) s_2 u_2 \leq x_{2_o} + x_{2_{in}}$$

$$x_3 + (1 + l_1 + l_2) s_2 u_2 \leq x_{3_o} + x_{3_{in}}$$

$$x_4 + (1 + l_1 + l_2) s_1 u_1 - s_3 u_3 - (l_1 + l_2) s_{14} u_4 \leq x_{4_o}$$

The goal function of the upper-level problem is defined analytically as a quadratic optimization problem:

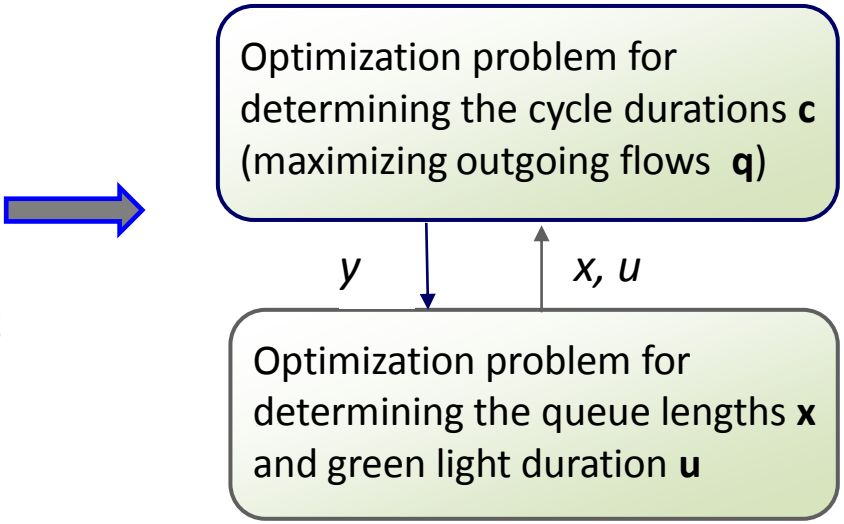
$$\min_y y^T y \qquad (3)$$

$$y_{min} \leq y \leq y_{max}$$

$$u_1 + u_2 = 0.9y_1 \quad u_3 + u_4 = 0.9y_2 \quad u_5 + u_6 = 0.9y_3 \quad u_7 + u_8 = 0.9y_4$$

$$u_9 + u_{10} = 0.9y_5 \quad u_{11} + u_{12} = 0.9y_6 \quad u_{13} + u_{14} = 0.9y_7 \quad u_{15} + u_{16} = 0.9y_8$$

The new intelligent method for urban traffic control



IV. NUMERICAL EXPERIMENTS AND RESULTS

The bi-level problem is modelled in MATLAB environment. A sequence of solving lower and upper bi-level problems is implemented. The optimal values of control variables, splits and cycles are obtained as solutions of the bi-level optimization problems (2) – (3).

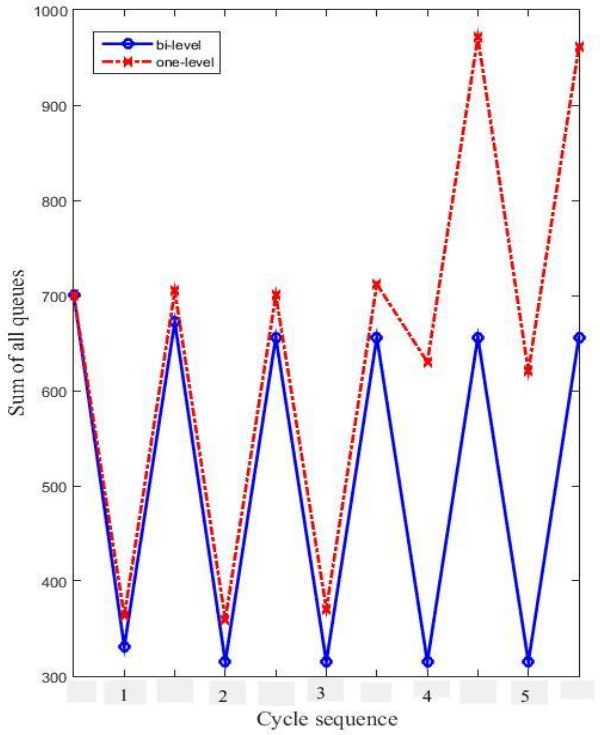


Fig. 2 Dynamics of the sum of all queues

The optimal results of bi-level problem are compared with classical optimization of one-level problem. The last is solved with the MATLAB function "quadprog". The comparison of the both optimization solutions is done by evaluation of the total waiting vehicles in the network, Fig.2.

Comparisons of queues evaluated by both models - bi-level and classical optimization

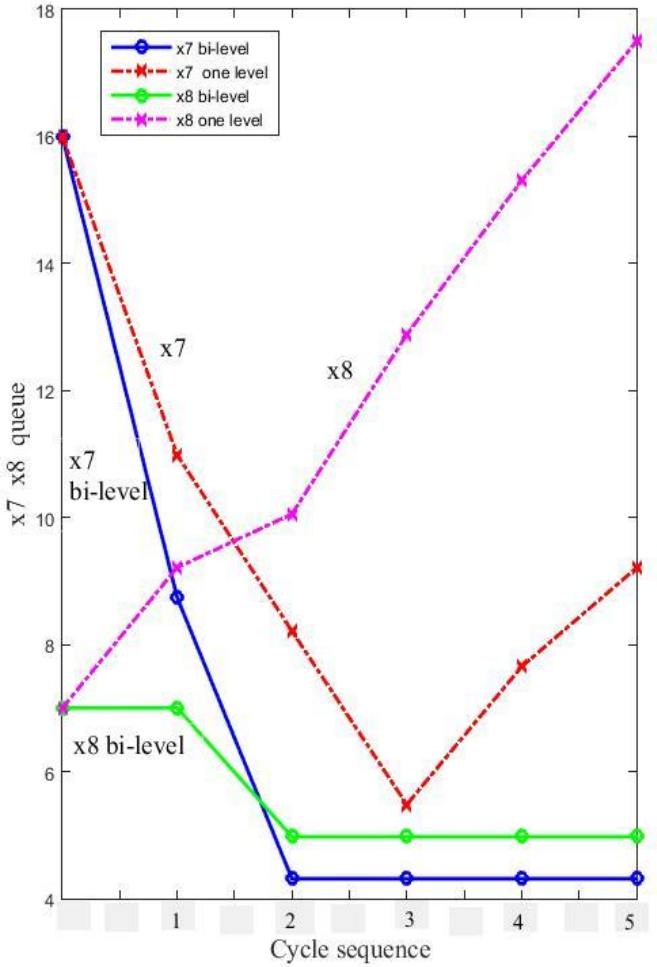


Fig. 3 Comparison for *x*7 and *x*8 queues

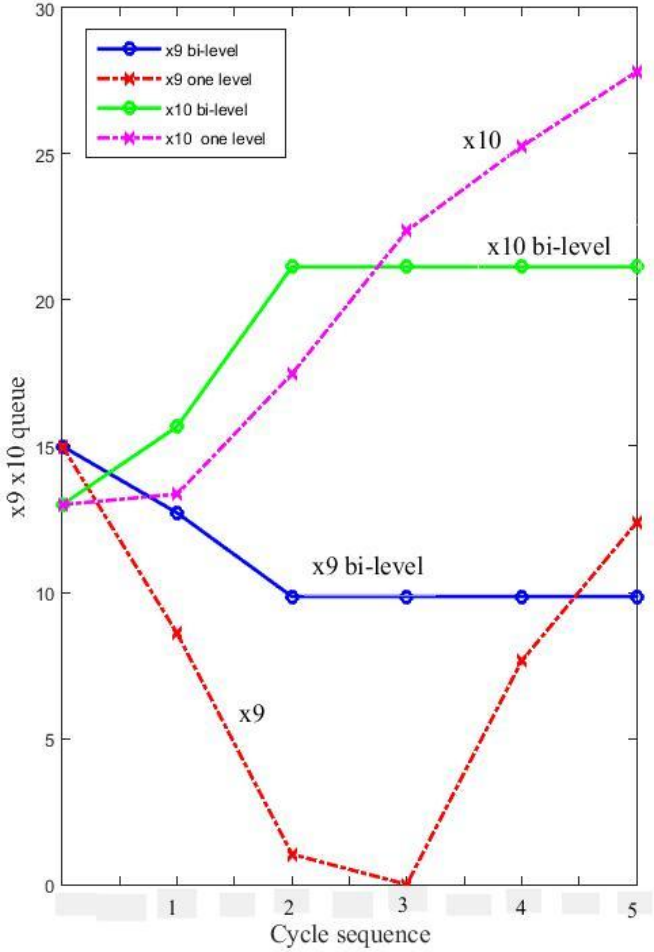


Fig. 4 Comparison for *x*9 and *x*10 queues

Comparisons of queues evaluated by both models - bi-level and classical optimization

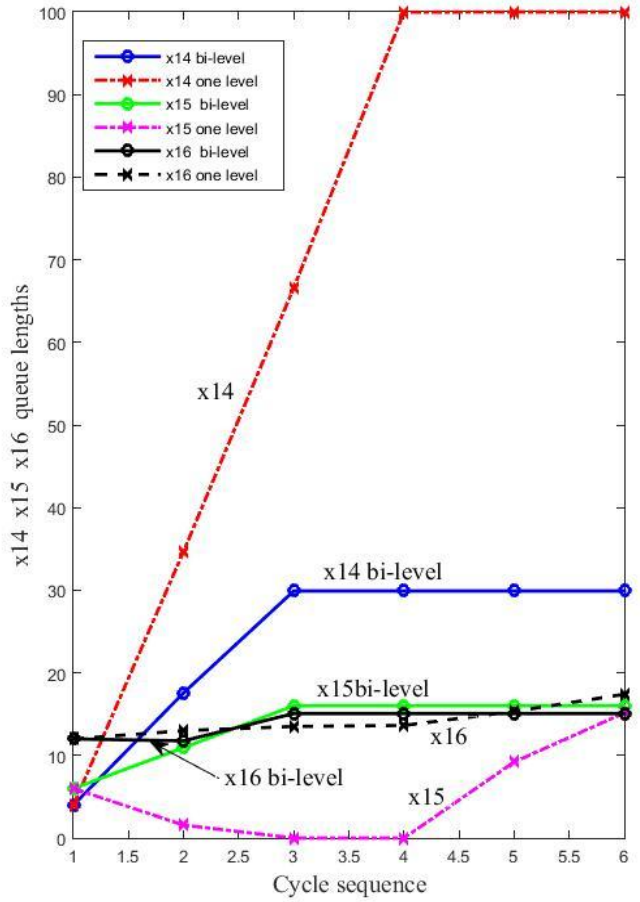


Fig. 5 Comparison for *x*14 , *x*15, x16 queues

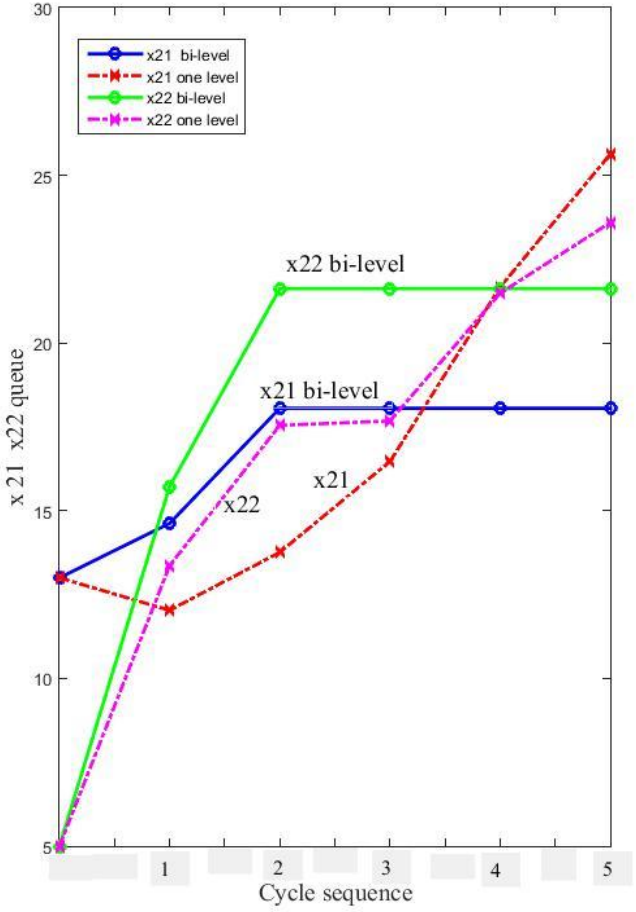


Fig. 6 Comparison for *x*21 and *x*22 queues

Comparisons of queues evaluated by both models - bi-level and classical optimization

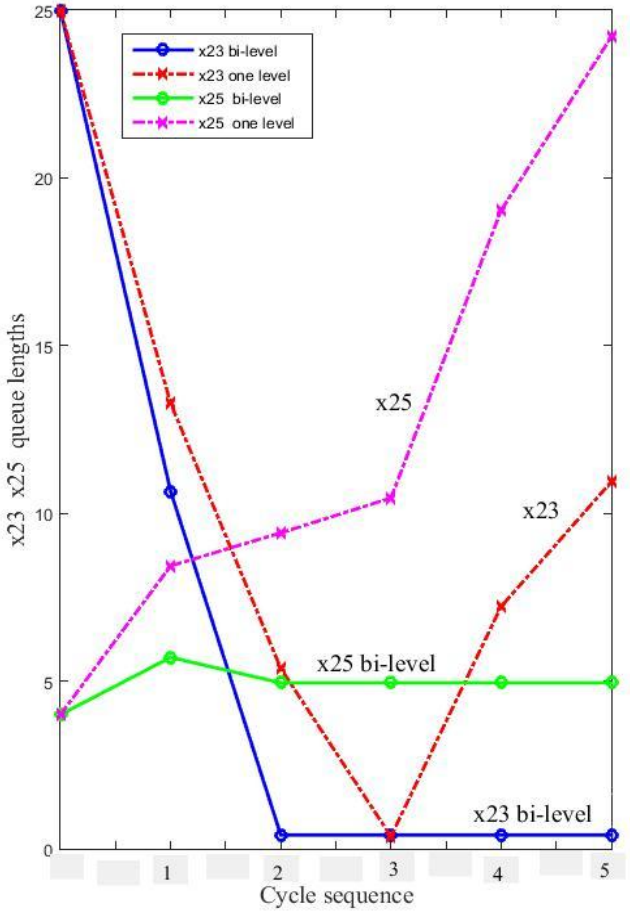


Fig. 7 Comparison for *x*23 and *x*25 queues

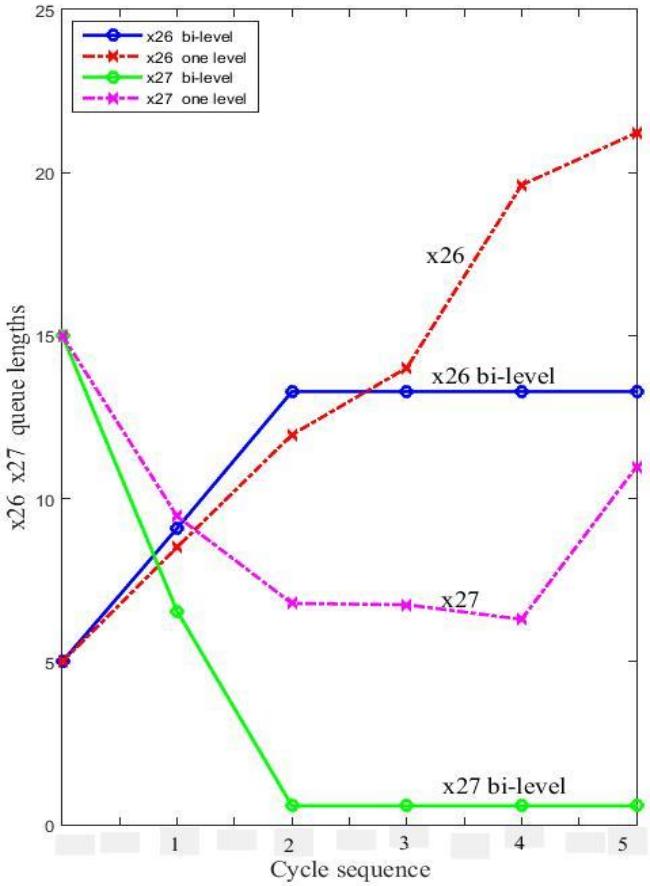


Fig. 8 Comparison for *x*26 and *x*27 queues

Comparisons of queues evaluated by both models - bi-level and classical optimization

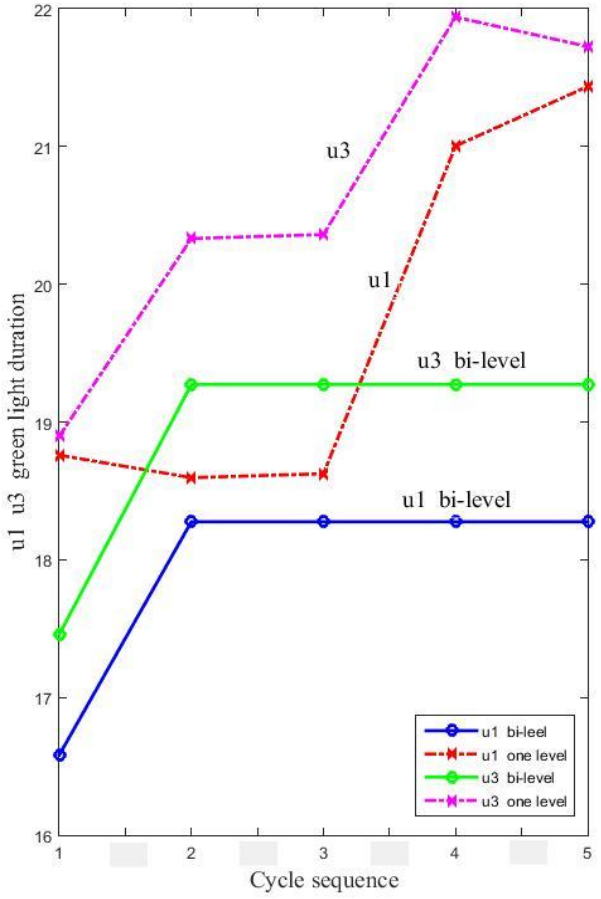


Fig. 10 Comparison for *u1* and *u3* green lights

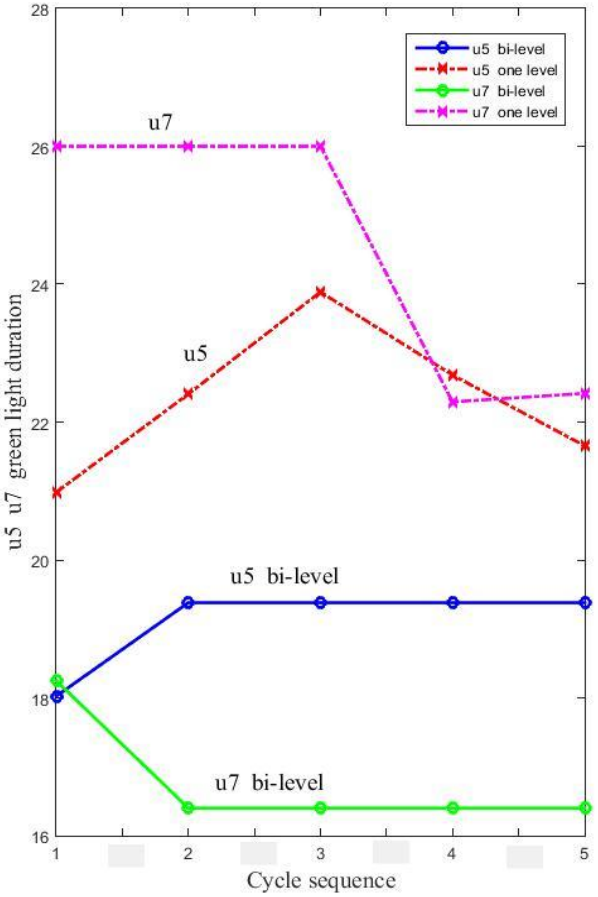
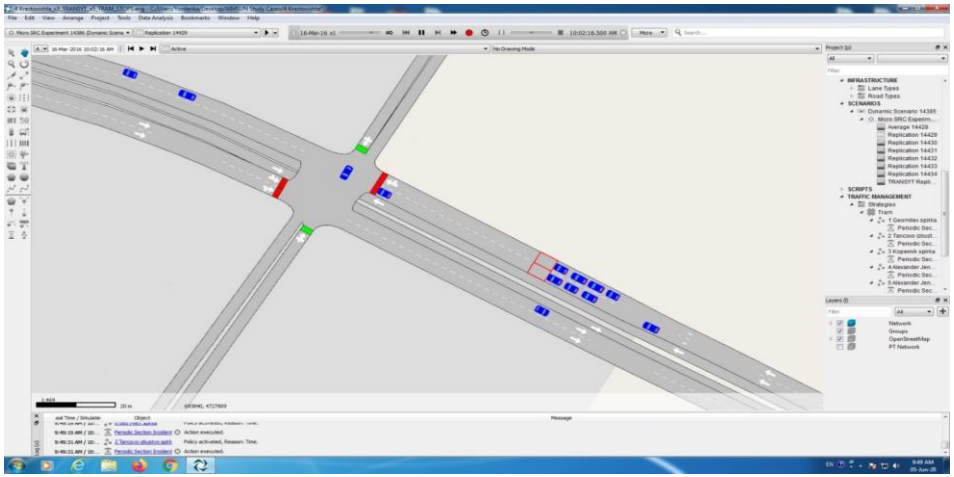


Fig. 11 Comparison for *u5* and *u6* green lights

CONCLUSIONS

This research makes an integration of two important control variables of the traffic lights: splits and cycles. The integration is performed by new form of definition the control problem in bi-level formalization.



The lower level problem gives the optimal values of queue lengths *x* and the durations *u* of the green lights.

The upper level problem gives the optimal values of the traffic lights cycles *y*

The numerical simulations give advantages to the bi-level problem, in comparison with the classical optimization

The added value of this research is the prove of the advantages of the bi-level optimization by the traffic control simulation results which lead to decreasing the traffic queue lengths .

Theoretical results

- **Development of new methods for traffic control by hierarchical approach and bi-level optimization.**
- **Determination and solution of interconnected optimization problems for traffic control application;**
- **Synthesis of new algorithms for fast solution of multilevel hierarchical problems**

Research and application results:

- **Synthesis of analytical approximation relations and their application for numerical algorithms for solving bi-level optimization problem;**
- **Expanding the application area of bi-level optimization for the intelligent traffic control.**

Project's site

http://hsi.iict.bas.bg/projects/transport/index.html

Scientific publications:

22 publications for the first phase of the project:

- **1 book**
- **1 chapter of book abroad**
- **8 papers in journals with SJR, Q2**
- **15 publications, indexed in Scopus**

Acknowledgments

The research is funded
by Project KP06-H37/6
“Modelling and optimization of urban traffic in network of crossroads”
with the Bulgarian Science Fund