AUTONOMIC COMPUTING APPLICATIONS FOR TRAFFIC CONTROL

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1. Introduction

The information technologies require competent influence of IT specialists.

As the variety of proposed information services increase very fast, the IT specialists can not maintenance these IT services and their interaction which leads to impossibility for servicing all these systems, computers, communications and customers.

In the near future as the technologies' development and their variety has higher speed than their maintenance, a shortage of corresponding IT specialists is expected and the system "customer-services" will not be able to work.

To overcome this negative tendency Paul Horn, vice-president of IBM alarmed the scientific society in 2001 and proposed the scientists directions for thinking and research.

His idea is based on creation of new opportunities for decision making and essential calculation and communication operations without human participation, i.e. development of automatic systems.

The efforts have to be directed to development of computer systems, which are self-controlled at the same manner like the human's nervous system - it regulates and protects our body.

These systems are known like autonomic computing systems.

CONCEPTS OF AUTONOMIC COMPUTING SYSTEMS

The following 8 characteristics of autonomic computing systems are given by IBM [2]:

1. The autonomic computing systems have to know themselves - their components have to present the system's identity. As the system can exist on many layers, it is necessary detailed knowledge of the state of all its components, their capacity, final states, and relations to other systems in order to be controlled.
2. The autonomic computing systems must change their structure in some conditions and self-configured. This pre-structuring has to become automatically by dynamical adaptation to the changing environment.

3. The autonomic computing systems have to optimize their work. They have to observe their consisting elements and working flows in order to reach the preliminary put goals.

4. The autonomic computing systems have to be able to self-heal themselves from usual or unusual events which can damage some system’s elements. They have to find problems or potential problems and to discover alternative ways for using resources or to reconstruct the system in order to keep its normal functioning.

5. The autonomic computing systems have to be able to protect themselves. They have to find, identify and protect from different attacks, to maintain the safety of the system.

6. The autonomic computing system has to know its environment and to act according it. It has to find and generate rules how to interact with the neighbour systems. It has to use the most appropriate resources and if they are not available to negotiate with other systems to take them from these systems. It has to change itself and the environment or it has to be able to adapt it.

7. The autonomic computing systems can not exist in closed environment. They have to act in various environments and to apply open standards. They do not perform preliminary done decisions. They have to continuously make decisions.

8. The autonomic computing system has to predict the necessary optimal resources for accomplishing the current tasks. The system has to satisfy quality of services and to arrange the information-technological resources in a manner to decrease the distance between the business and personal goals of the customer and the IT instruments.

AUTONOMIC BEHAVIOUR FOR TRANSPORTATION SYSTEMS

The autonomic behaviour for the transportation systems is inspired mainly from the complex nature of the traffic phenomena and the necessity to resolve the associated decision making problems by the road operators.

The complexity of the traffic management comes from the requirements to solve a set of management traffic tasks and the technical devices and systems, which can provide parts of the needed functionality of the traffic control system.

A prospective way to tackle the complexity of the problem for traffic management is to apply the concept for the autonomic behaviour of several local control subsystems and to coordinate their functionalities in a multilevel control system.

AUTONOMIC BEHAVIOUR FOR TRANSPORTATION SYSTEMS

Because the traffic management system is a distributed system with local subsystems, each operating with its own goal and functionality, the challenge is to provide self-∗ properties to each subsystem and to create a cohesive management policy that will integrate the subsystems' capabilities taking into account the subsystems interactions.

This will allow the control policies and local control influences to adapt the overall traffic control accordingly

AUTONOMIC APPLICATION IN TRAFFIC CONTROL

This section illustrates the application of bi-level optimization model [5] for implementation of autonomic properties in traffic light control.

The idea of the experiment was to increase the scale of the arguments of the optimization problem.

Thus in a bi-level formulation the solution of the problem is not only

the relative duration of the green lights but

the durations of the cycles of the traffic lights as well.

Thus in a common control process the transport system autonomically turn to optimal values of both important parameters of the transport crossroads.

Two crossroad sections interrupt the main stream of the traffic flow, presented on the fig.1. The formal model, which is used to present the dynamics of the waiting vehicles in front of the traffic lights, is related to the conservation law:

$$x(k+1) = x(k) + q_{in}(k) - q_{out} \qquad (1)$$

- $x_i(k)$ - the number of waiting vehicles,
- q_{in}, q_{out} - the inflow and the outflow of vehicles to the crossroad section,
- k - the control discrete period

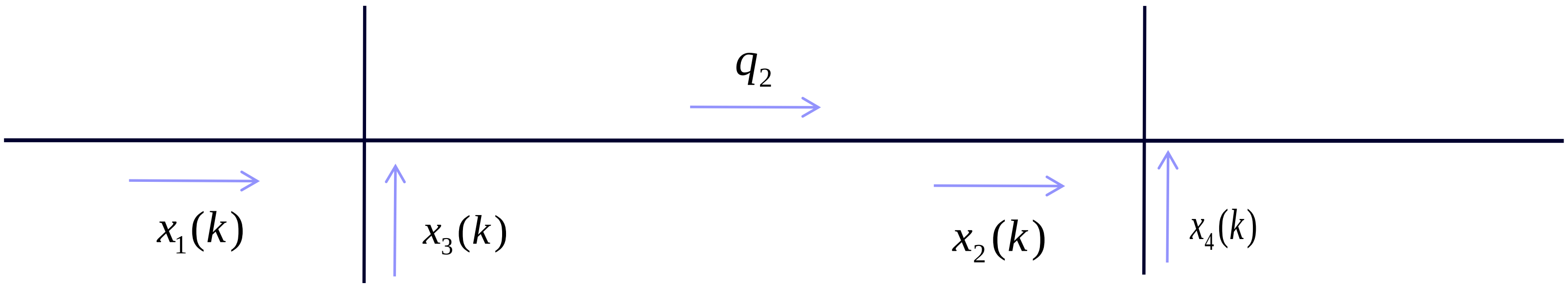

Fig.1. One way intersection measuring scheme

The optimisation problem for finding the relative duration u_i of the green lights is:

$$\min_{u_1,u_2}(a_1x_1^2 + a_2x_2^2 + a_3x_3^2 + a_4x_4^2 + r_1u_1^2 + r_2u_2^2) \qquad (2)$$

$$x_1(k+1) = x_1(k) + q_{1in}(k) - s_1u_1c$$

$$x_2(k+1) = x_2(k) + s_1u_1c_1 - s_2u_2c_2$$

$$x_3(k+1) = x_3(k) + q_{3in}(k) - (L_1c_1 - u_1c_1)s_1$$

$$x_4(k+1) = x_4(k) + q_{4in}(k) - (L_2c_2 - u_2c_2)s_2$$

where $x_{i0} = x(0),\ i = 1,4$ - the initial known values

$c_l, l = 1,2$ - the time cycles of the traffic lights (constant values)

$u_i, i = 1,2$ - relative durations of the green lights for the two sections

$s_j, j = 1,2$ - the capacities of the crossroad sections

$L_m, m = 1,2$ - the relative duration of the amber light

This problem is widely used to evaluate the optimal relative durations $u_i, i=1,2$ assuming that the time cycle c_i are known, according to predefined reference plans.

The autonomic considerations insist the traffic light cycles c_i to be adapted also to the transport behaviour.

Thus c_i have to be defined as solutions of appropriate optimization problem instead to be used as predefined parameters

Here a bi-level optimal problem is introduced,
which results in increasing the solution space of the optimization.

The idea of the experiment was to increase the scale of the arguments of the optimization problem.

Thus, both the relative duration of the green lights u_i

and the time cycles c_i

will be evaluated like solutions of a common optimization problem

This autonomic framework is implemented by the following bi-level problem formulation.

By solving the classical problem (2) with different values of c_i the solutions

$u_j(c_j)$, j=1,2 are inexplicit functions of the time cycles .

For an optimal decision for the durations of c_i an additional optimization problem is defined, fig.2

The upper level optimization problem is defined to maximise the traffic flow on the arterial road (q_2 between the two crossroad sections – fig.1).

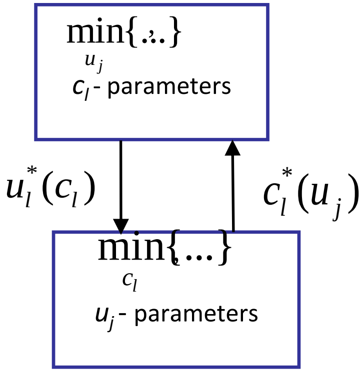

Fig.2. Bi-level formalization of the optimization problem

Following the flow modelling the traffic flow q_2 is proportional to the average speed v and the density ρ_2 of the flow,

$$q_2 = v\rho_2$$

Applying the Greenshield approximations [1] for the relation $v(\rho)$, fig.3, it follows

$$v = v_{free}(1 - \rho_2 / \rho_{\max})$$

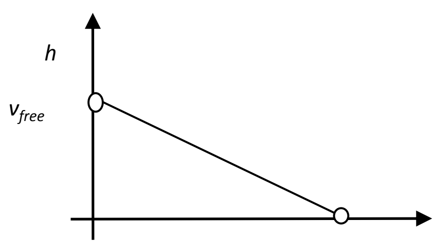

Fig.3. Linear approximation

which applies values v_{free} for the free speed and critical density $\rho_{\max}$.

Using these physical considerations, the traffic flow q_2 is

$$q_2 = v(\rho_2) = v_{free}\rho_2 - \rho_2^2 v_{free} / \rho_{\max}$$

The flow density ρ_2 is evaluated as the number of vehicles x_2 on the road with length L_2 , or

$$\rho_2(x_2) = x_2 / L_2$$

$$q_2(x_2) = \frac{v_{free}}{L_2} x_2 - \frac{v_{free}}{\rho_{\max} L^2} x_2^2$$

The upper level optimization problem has engineering meaning in maximization of the traffic flow $q_2(x_2)$

$$\max_{c_1, c_2} \{q_2(x_2(c_1, c_2))\} = \max_{c_1, c_2} \left\{ \frac{v_{free}}{L_2} x_2(c_1, c_2) - \frac{v_{free}}{\rho_{\max} L^2} x_2^2(c_1, c_2) \right\}$$

where the problem solutions are the time cycles $c_l, l = 1,2$.

$$\max_{c_l, l=1,2} \left\{ H(c_l) = q_2(x_2(c_l)) - c_l^T h c_l \right\} \tag{3}$$

Using $x_2(c_1, c_2)$ from (2), the upper level optimization problem becomes

$$\max_{c_1, c_2} \left\{ x_2(c_1, c_2) - \frac{1}{\rho_{\max} L} x_2^2(c_1, c_2) - h(c_1^2 - h_2 c_2^2) \right\} \quad (4)$$

$$x_2 = x_{20} + u_1 s_1 c_1 - u_2 s_2 c_2$$

The particular form of the optimization problem (2) allows the solutions u_i to be derived as analytical functions towards c_i or

$$u_1(c_1, c_2) = \frac{2x_{10} - x_{20} - 2x_{30} - x_{40}}{5 s_1 c_1} + \frac{s_2 c_2}{5 s_1 c_1} + \frac{2}{5} \quad (5)$$

$$u_2(c_1, c_2) = \frac{x_{10} + 2x_{20} - x_{30} - 3x_{40}}{5 s_2 c_2} + \frac{s_1 c_1}{5 s_2 c_2} + \frac{2}{5}$$

$c_1 \neq 0 \qquad c_2 \neq 0$

Using (5) the upper level optimization problem (3) is

$$\max_{c_1,c_2}\left\{H(c_1,c_2)=x_2(c_1,c_2)-\frac{1}{\rho_{\max}L}x_2^2(c_1,c_2)-c_1^2-c_2^2\right\} \quad (6)$$

$$x_2 = x_{20} + u_1 s_1 c_1 - u_2 s_2 c_2$$

$$c_1, c_2 \geq 0$$

where u_i are derived in (5).

The experiments, provided for the traffic network used the initial data are the following

$x_{10} = 70$ $\quad s_1 = 24 vehicles/\min$

$x_{20} = 60$ $\quad s_2 = 21 vehicles/\min$

$x_{30} = 50$ $\quad s_3 = 24\ vehicles/\min$

$x_{40} = 30$ $\quad s_4 = 18\ vehicles/\min$

L=800 m $\quad \rho_{\max} = 0.175 vehicles/m$

The experimental results of the bi-level formulation have been compared with the case of optimization of the green lights durations u_j but with constant values of $c_l, l = 1,2$

For the queue lengths for the arterial direction x_2 in front of the crossroad section a comparison between constant (dashed line) and controlled time cycle has been performed

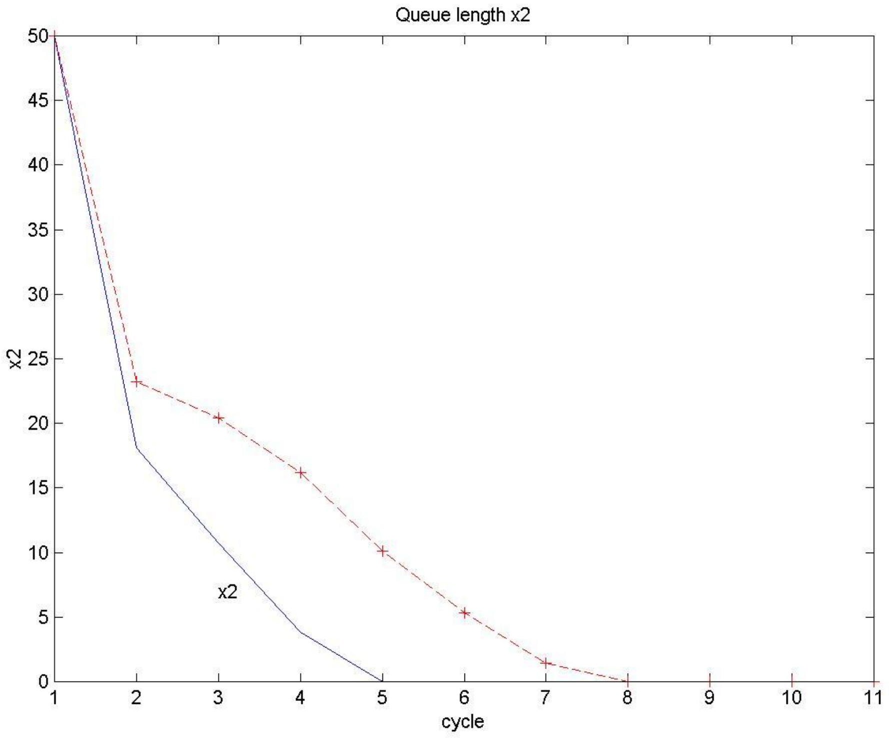

Fig.4 Queue length x_2 towards cycle k

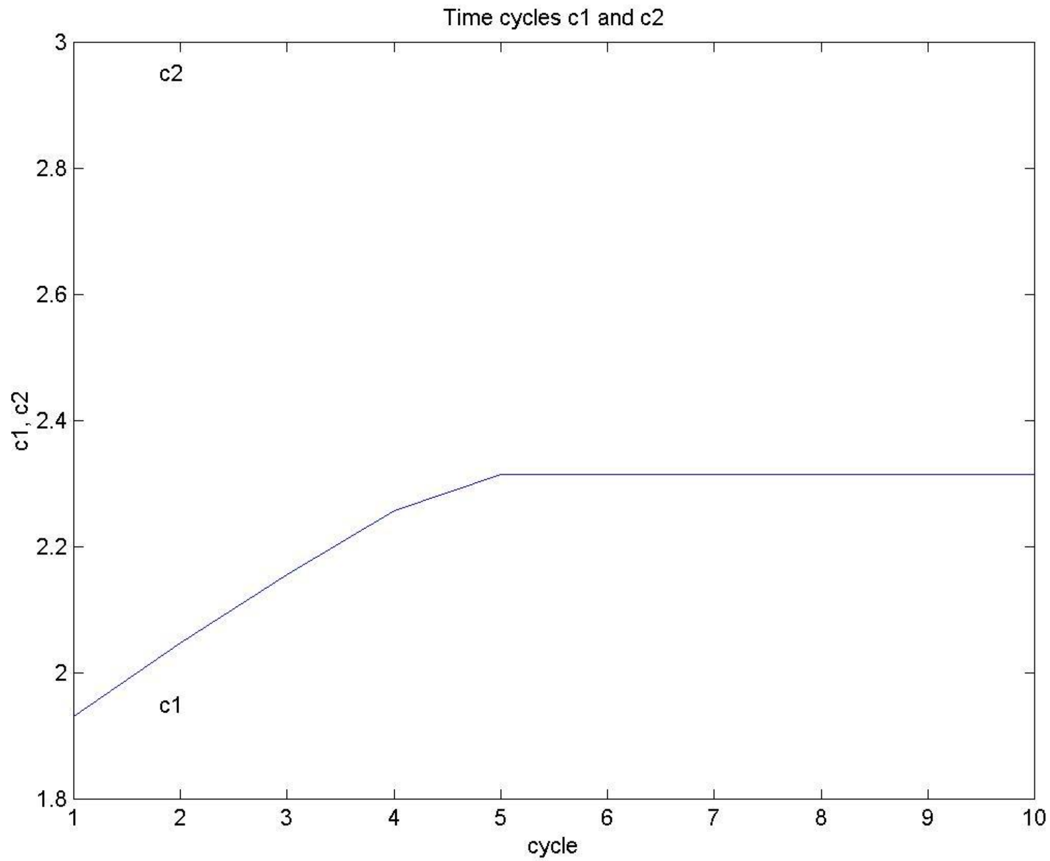

Fig.5 Time cycles changes

An integral assessment of the bi-level control policy is presented in fig.6 by evaluating the total queue length x_2 for the overall control horizon.

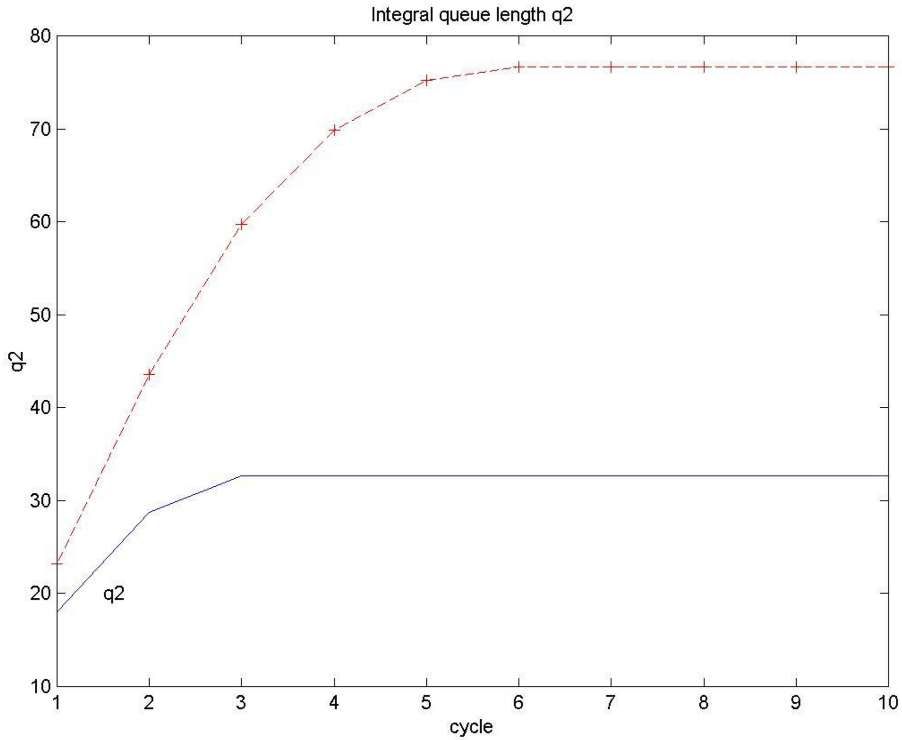

Fig.6 Integral queue length q_2 towards the cycle

4. Conclusions

•The implementation of autonomic concept in complex transportation systems is not only an academic and research domain.

• The autonomicy can be achieved by applying multilevel optimization for the control process.

• The paper motivate that the multilevel approach has potential for the formalization of autonomic functionalities.

• The example provided demonstrate the benefit of bi-level formulation in control of traffic lights.

• Thus, an increase of the transport parameters, defined as solutions of optimization problems is achieved.

• This increase of the space of the optimal solution in traffic system corresponds to the requirement for autonomic behavior od the control system.

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