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Intelligent Transportation Systems (ITS), crossroad control, video surveillance, ITS efficiency

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EFFICIENCY OF INTELLIGENT TRANSPORTATION SYSTEMS

Nowadays the number of vehicles in the cities is growing very fast. Loading on street intersections, traffic jams, wasting fuel and air pollution is increasing also. One of the ways to solve these problems is creating Intelligent Transportation Systems (ITS) and efficiency increasement of these systems. Quality parameters for ITS systems are: efficiency of data collecting system, volume and effectiveness of control system, adaptive and efficiency of algorithms.

SPRAWNOŚĆ INTELIGENTNYCH SYSTEMÓW TRANSPORTU

W obecnych czasach liczba pojazdów w miastach rośnie bardzo szybko. Wzrastają również: obciążenie skrzyżowań ulic, korki, straty paliwa i zanieczyszczenie powietrza. Jednym ze sposobów na rozwiązanie tych problemów jest stworzenie Inteligentnych Systemów Transportu (ITS) i zwiększenie sprawności tych systemów. Parametry jakości systemów ITS to: sprawność systemu zbierania danych, objętość i skuteczność systemu sterowania, elastyczność i sprawność algorytmów.

1. INTRODUCTION

ITS purpose is to gather information about traffic conditions and traffic flows in roads and to present it in non-distorted form for control systems (GPS, route control and creating public transport control systems, commercial transport control systems, electronic payment and tax collecting systems, etc.) Control systems themselves can be defined with qualitative parameters: controlling scope, expedition, adaptation, controlling algorithm and collecting systems efficiencies, variety and utility of the information they deliver.

Intelligent electronic transportation control system usually contains such main parts: 1) information collecting subsystem; 2) information processing subsystem; 3) information

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transmission subsystem; 4) controlling subsystem 5) subsystem of interfaces between separate hierarchical levels.

Electronic ITS contain a set of technical tools connected into general information processing complex. Since at least two systems working according common algorithms and connected using interfaces may be considered as minimal integrated system, in that way electronic ITS also is an integrated system [1] (video surveillance signal processing, controlling system, etc.). The main part of the system that collects information from video cameras consists of digital video cameras and special video signal processing and transmitting cards that are installed in proper road sections and crossroads. Such system helps to get the real time information regarding traffic conditions in road sections of interest; therefore all this information can be efficiently used to control the transport traffic. All signals from digital video cameras are transmitted to central systems that analyze traffic flows. Presently the statistical information is collected in the real operating objects where video cameras with software support are connected that are able to recognize cars and their license numbers. When this information is collected it is possible to evaluate efficiency of information collecting subsystem in detail.

2. ITS DATA ACQUISITION TECHNOLOGIES

In order to select optimal ITS structure, subsystems, and location points it is important to evaluate efficiency of these systems. General (overall) ITS system efficiency can be separated into two parts: 1. efficiency of information acquisition and transmission and degree by which this information satisfies needs; 2. control quality: parameters of control extent, adaptability, and partial maintenance duration reduction of transport means. Degree by which information required by ITS satisfies needs can be evaluated using data acquisition systems of different technologies [2]. General ITS data acquisition technology adequacy to required gather information

$$Q_{Techn} = \frac{\sum_{i=1}^{n} q_{ij} \cdot \rho_i}{n}; \tag{1}$$

here j – number of data acquisition technology, i – number of information type, q_{ij} - normalized data acquisition adequacy index of j-technology for gathering of particular i-information, ρ_i - normalized significance coefficient of information of i-type. After performing expert survey the data has been received which evaluates the adequacy of currently used technologies to gather required information, is presented in table 1.

After analyzing the gathered information it can be seen, that the highest coefficient Q_{Techn} was received when digital video signal processing technology was applied. A conclusion can be made on the basis of this fact, that image monitoring and digital analysis supplies biggest amount of information required by ITS system: count of cars, length of car queue, car classification, random alarm events and etc.

Table 1

Evaluation of technology adequacy to required to gather information using expert survey technique

Technology / Information type	Video image detection	Pneumatic road tubes	Inductive loop	Microwave radar	Infrared detectors	Vehicle marking with RFID tags
Vehicle counting	0,9	0,9	0,9	0,8	0,7	0,9
Length of standing cars queue	0,7	0,1	0,1	0,5	0,1	0,1
Vehicle classification	0,7	0,8	0,6	0,6	0,1	0,8
Vehicle speed	0,6	0,6	0,1	0,9	0,1	0,1
Accidents	0,7	0,1	0,1	0,1	0,1	0,1
Climate conditions	0,3	0,1	0,1	0,1	0,1	0,1
Vehicle identification	0,8	0	0	0	0	0,9
$Q_{Techn} = \frac{\sum_{i=1}^{n} q_{ij} \cdot p_i}{n}$	0,67	0,37	0,27	0,43	0,17	0,43

3. ITS EFFICIENCY

Efficiency of overall Intelligent Transportation System, which uses video cameras to gather information, depends on the following parameters: efficiency of video cameras E_K; efficiency of placement of video cameras E_I; system of data acquisition via video cameras operation efficiency E_S; efficiency of information transmission networks E_T; efficiency of control algorithm E_A.

Efficiency of video cameras. Some of main features of video cameras are directional characteristic, resolution, sensitivity to lighting, focal length of lenses, etc [3]. All these features are characterized by the set $\{L_j\}$ of indexes ($j=1,L_J$), values of these indexes are expressed by the set $\{l_j\}$. Thus technical level of video camera according to all technical indexes can be expressed using equation

$$Q_K = \sqrt{\sum_{j=1}^{L_j} (q_j \cdot \eta_j)^2} \, ; \tag{2}$$

here j – technical index of video camera; q_j - normalized value of parameter of j-index; η_j - significance coefficient of j-index.

Not all parameters of video cameras used to recognize vehicles means are equally significant (for example: number of TV rows in video camera CCD matrix is substantially more significant than high contrast [3]). Main technical indexes describing video camera are presented in table 2. Experimental and expert survey techniques are applied (by taking statistical averages) to determine significance coefficients of all indexes. Indexes will be numbered according to their importance. A grade is attributed to more important indexes:

$$g_{j/u=1} = m + 1 , \tag{3}$$

and for not so important

$$g_{j/u=2,3...m} = m - u + 1 ; \tag{4}$$

here u - number of j-index. Therefore significance coefficient expression will be

$$\eta_j = \frac{g_j}{\sum_{i=1}^{m} g_i}. \tag{5}$$

Not only image indexes are important for ITS systems, but also expenses of video camera installation [1]. It is necessary to establish a graph of each camera type quality coefficient dependency on cost in order to select most suitable video cameras, on one axis of which technical level coefficient (Q_{Ki}) is represented, and the value of economic index (cost) (C_{Ki}) for this camera type is represented on the other axis (Fig.1).

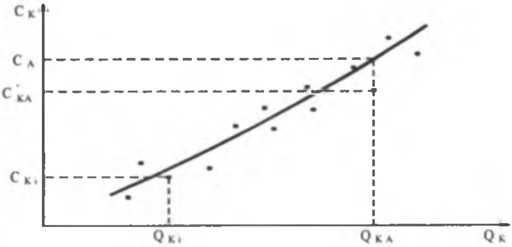

Fig.1. Relation between technical level and price

This curve can be used for evaluation of general (overall) efficiency of video cameras. Consequently selection efficiency of particular video camera

$$E_{KA} = \begin{cases} 1 - \dfrac{C'_{KA} - C_{KA}}{C_{KA}} K_T, when C'_{KA} > C_{KA}; \\ 1, when C'_{KA} \le C_{KA} \end{cases} \tag{6}$$

Efficiency for placement of video cameras. Location of video cameras also has influence on ITS efficiency. When analyzing the work of video cameras active road areas are presented graphically, in which video camera registers means of vehicles moving along the road.

Placement efficiency of video camera can be evaluated by means of mounting it in particular road section. Video camera monitoring places and required to monitor road places are shown in Fig.2. Therefore video camera application efficiency can be expressed using equation 7 and 8

$$E_{In} = \frac{Q_{In}}{h_n \cdot l_n}, \tag{7}$$

here h and l - length and width of required to monitor road traffic line, Q_K - part of required to monitor road traffic line area monitored by video camera.

Q_K can be associated with technical parameters of video camera in the following way:

$$Q_{Kn} = S_{In} - h_n \cdot l_n; \tag{8}$$

here S_{In} - total area monitored by video camera.

In order to increase recognition reliability of cameras, redundancy of video cameras can be implemented: adjacently placed cameras can also partly monitor the area monitored by another camera. Let's consider a system, consisting of two video cameras, when both cameras monitor single road section, but different adjacent traffic lines, as depicted in Fig.2.

Assume, that no-failure probabilities of both video cameras are the same, i.e.

$$P_1 = P_2 = P. \tag{9}$$

Thus, efficiency of determining, that vehicles mean moving along the traffic line j will be successfully recognized, can be found in the following way:

$$E_{lj} = \sum_{n=1}^{n} E_{ln} \cdot E_{Kn} \cdot E_{Sn} \cdot H_{ln}; \tag{10}$$

here E_{Kn} - efficiency of camera with index n; E_{Sn} - efficiency of n-channel of data acquisition via video cameras; E_{ln} - video camera utilization efficiency; H_{ln} - the ratio of area monitored by n-camera in j road traffic line and required to monitor traffic line section area, which can be expressed as:

$$H_{ln} = \frac{Q_{lj}}{S_{lj}}; \tag{11}$$

here Q_{lj} - part of required to monitor road traffic j-line area monitored by video cameras, S_{lj} - required to monitor area of j road traffic line.

Efficiency of video camera installed in particular road section is defined as a probability of task accomplishment (i.e. car recognition probability). Car recognition probabilities of different video cameras, lenses and different digital image processing algorithm systems are expressed differently. Main video camera task accomplishment probability can be expressed in the following way:

$$P_S = P_0 + (1 - P_0)(1 - f(t)); \tag{12}$$

here P_0 - probability, that car recognition system will recognize a car in an image recorded by video camera; $f(t)$ – function of time, which defines, that a car appeared in the coverage zone will not be recognized for time t.

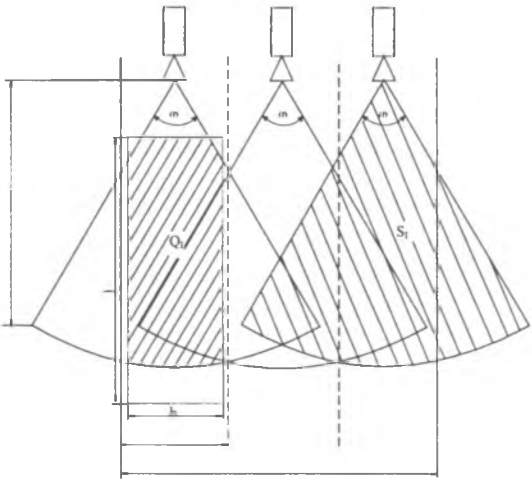

Fig.2. Placement of video cameras over the road

When the coverage zone of one video camera intersects the coverage zone of another video camera, redundancy scheme of car recognition systems is realized. Then efficiency of the first recognition system

$$P_1 = P_{01} + (1 - P_{01})(1 - e^{A_1 t_1}), \tag{13}$$

respectively for the second system

$$P_2 = P_{02} + (1 - P_{02})(1 - e^{A_2 t_2}). \tag{14}$$

Overall efficiency of both systems

$$P_{S12} = 1 - (1 - P_1)(1 - P_2). \tag{15}$$

Therefore, although the first car recognition system can separately assure P_1 efficiency, when a second system is present it increases recognition task fulfilment probability only by ΔP_1 quantity:

$$\Delta P_1 = P_{12} - P_2. \tag{16}$$

4. EXPERIMENTAL AND MODELLING RESULTS

Three crossroads were selected in Kaunas for the surveillance of traffic jamming. Traffic heaviness in all the crossroads has been surveyed for one hour between 4-5 p.m. and 7-8 p.m., five weekdays for three weeks. Detailed investigation was accomplished in the crossroad of Vyduno ave. and K. Petrausko st. in Kaunas. Incidents are given in histograms of flow emergence intervals in Figures 3 – 4. Separately evaluated are the incoming through each channel (street) into the accumulator (crossroad) $S_{in\ i}$ incident flow (the flow of cars coming to the crossroad) and the outgoing $S_{out\ i}$ incident flow (the flow of cars going out of the crossroad). Times of traffic-light opening are constant.

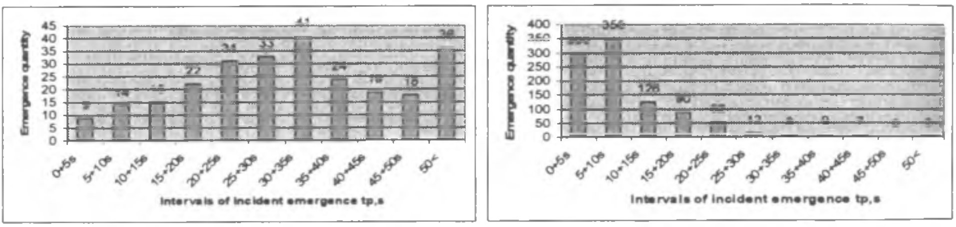

Fig.3. A histogram of all the intervals for emergence of the incoming incident flow S_{in1} and S_{in2}

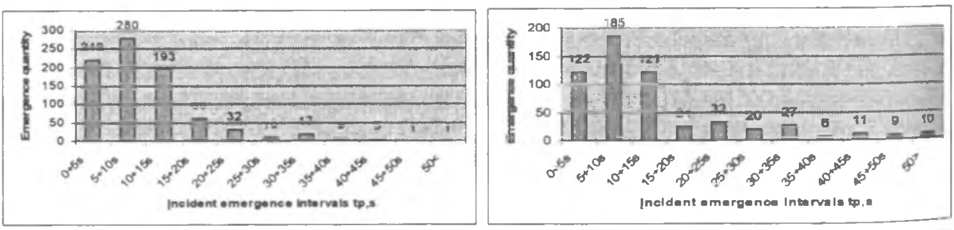

Fig.4. A histogram of all the intervals for emergence of the incoming incident flow S_{in3} and S_{in4}

Schemes of crossroad flows are made for modelling see Fig.5. In this Figure the K is the accumulator corresponds to a crossroad because every crossroad operates analogically for the accumulator [4]. The main parameter of the accumulator – time of retention t_u. $S_{in\ j.i}$, the incoming car flow both which are oncoming in the direction „j“ and which will be going in the direction „i“. S_{out} – the flow of cars leaving the crossroad in the direction „i“. We can see a scheme of flows of one crossroad in Figure 5. Given a crossroad of traffic with several traffic lines of different directions (straight, to the right, to the left) we know how traffic flows leaving the crossroads would distribute, e.g.: $S_{out}=S_{in4.2}+S_{in3.2}+S_{in1.2}$.

While analyzing these flows we may foresee traffic flows in other adjacent crossroads as well. A scheme of traffic flows of all the city may be made according to this principle (see Fig.6). The quantity of traffic flow may change on the way from a crossroad to another one (pull off or drive into the road from a yard, etc.); therefore a divisor in which flows S_+ and S_- are summed and deducted is interposed before the crossroad. The flow is also distributed in the same divisor with certain probabilities for going straight, to the right and to the left.

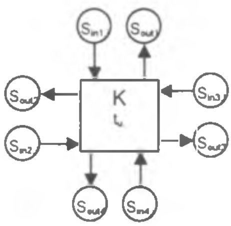

Fig.5. A scheme of flows for one crossroad

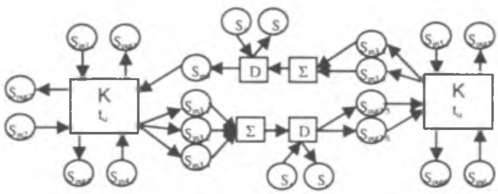

Fig.6. A scheme of the connection for flows of two crossroads

According to Markov‘s Theory of Mass Service Systems [5;6], the average time of opening of a crossroad. The parameter μ is a reciprocal to the average duration of the service of request.

$$\mu = \frac{1}{\overline{T}_{apt}} = \frac{1}{30} = 0{,}033 \ \ 1/s^{\ 1}; \tag{17}$$

For modelling was chosen M/M/1 system. M/M/1 system with a row consists of one service line and the length of the row is unlimited. The average time of a car waiting in a row

$$\overline{w} = \frac{\rho}{2\mu(1-\rho)} + 1 \approx 18{,}3\ s^{\ 1};\ \text{Here}\ \rho = \frac{\lambda}{\mu} < 1. \tag{18}$$

The average time of a cell (car) being in the system (in the crossroad):

$$\bar{\tau} = \tau_{atml} + \bar{w} \approx 22{,}6s\ ^{1}; \tag{19}$$

here τ_{atml} is the time during which a car crosses a crossroad on the average after the green traffic light has switched on and $\tau_{atml} \approx 4{,}3s\ ^{1}$. The average number of cars standing in a row at a crossroad:

$$\bar{N}_{\rho} = \lambda \cdot \bar{w} \approx 13\ ^{1}; \tag{20}$$

here quantities as $\bar{w}$, τ_{atml}, $\bar{\tau}$, T_{apt}, $\bar{N}_{\rho}$, $\bar{N}_{sist}$ etc. are given in experimental quantities after accomplishing an investigation in a real crossroad of streets in Kaunas. Having analyzed the results given in Figures 7 ÷ 8 we can see that subject to a car flow we must also choose operational parameters of traffic lights (how much time to give for green and red signals). Given a heavy car flow the least average time of vehicle service $\bar{T}_{apt}$ is reached when T_{cikl} from 50 to 60 s (50 s for green and 50 s for red signals), and if given a little car flow the optimal service time is reached when we have a cycle time T_{cikl} from 30 to 40 s. The same also applies in summer and winter period (see Fig.9). Such a difference of results occurs due to the fact that in winter given a snowy and iced road an average time of service of one car vastly increases $\bar{T}_{apt}$ because all cars start and pass a crossroad considerably more slowly.

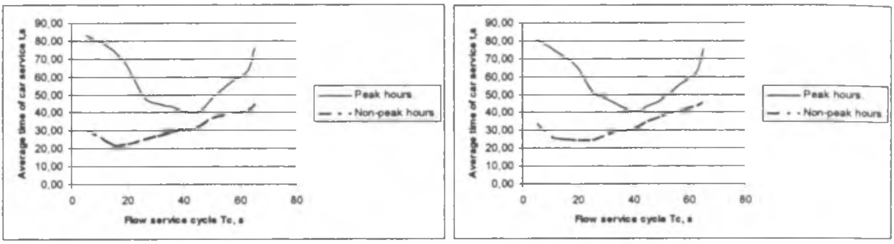

Fig.7. Dependence of average time of car service upon a service cycle (frequency of green and red signal cycle) during peak and off-peak periods

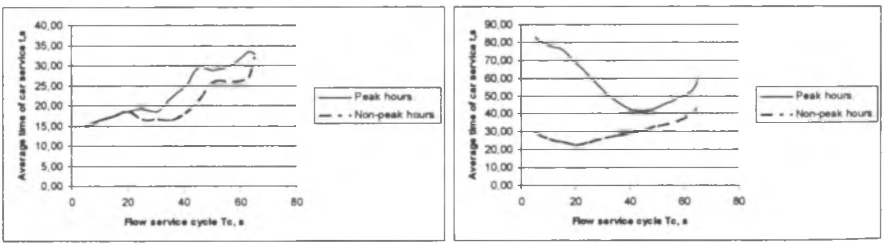

Fig.8. Dependence of average time of car service upon a service cycle (frequency of green and red signal cycle) during peak and off-peak periods

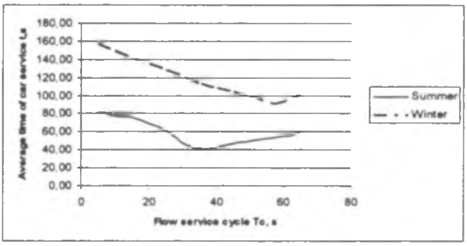

Fig.9. Dependence of average time of car service upon a service cycle (frequency of green and red signal cycle) during peak and off-peak periods in summertime and in wintertime

So crossroad control experiments were accomplished in the work using the designed imitative model. The investigation proved that: Given different numbers of requests $\lambda \approx 4s$ to $\lambda \approx 6.5s$ the average duration of the service of the request $\overline{T}_{apt}$ can be reduced even down to 30%. Given different weather conditions the duration of the service of the request changes automatically, consequently, even given the same number of requests $\lambda = const$. By changing cycles of traffic light operation it is possible to reduce the retention of every car even down to 35%.

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