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System for Search of Optimal Transport Routes

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Introduction

Rise of number of cars increases environmental pollution and also more and more time is spent *in traffic jams*. Traffic jams are harmful for two reasons (economic and ecological): waste of time and increase of environment pollution.

The following measures may be taken to reduce *traffic jams* effect:
- decrease of traffic density,
- installation of information systems warning about location of traffic jams and showing routes to avoid them.

This article analyzes the second possibility to partially solve the traffic jams problem.

Fast improvement of computers, automation systems, communications, mechatronic means allow *Intellectual Transport Control Systems* (ITCS) [1] to develop rapidly, which gives a possibility to optimally use ***existing*** infrastructure of city transport, and for the road users to choose the best (in accordance with the criteria chosen by the driver: *time*, *fuel consumption*, *accident risk* and etc.) route in the current situation.

Nowadays Geographic Information System (GIS) [2,3] are available to every road user and the range of such services is constantly developing and improving. At present the most universal are *GIS-TMC systems* (*navigation systems* with *TMC - Traffic Message Chanell*). The structural diagram of such system is shown in fig. 1.

The system structure is mostly determined by the range of informational sources. In common case the basis of the Traffic Information Centre (TIC) database contains fixed data:
- road and street network;
- regular parameters of roads and streets (length, speed limit, changes of traffic density during the day, etc.).

Unpredictable changes of infrastructure parameters are registered after receiving the information from electronic sensors, personnel of special services, road users and etc. These changes may be entered into the database automatically (if information is received from the sensors) or manually by an operator (if verbal information or results of video monitoring are registered).

The registered data and their changes are processed by TIC, after that they are passed to the road users by radio channels (through automobile or pocket PC – communicators, radio or stationary information boards).

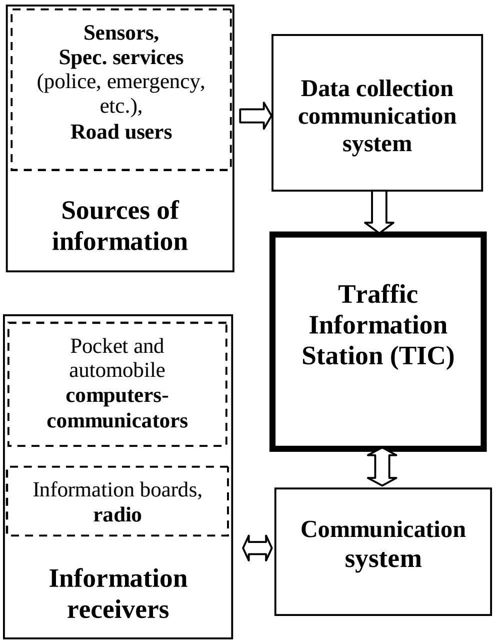

Fig. 1. Structural diagram of GIS-TMC system

The system drawbacks:
- expressed influence of human factor in the stages of both information collection and processing;
- although it is stated that the system operates in real time, in fact, considerable delay of information is possible, which is especially felt in the city.

The above mentioned drawbacks of GIS-TMC systems most of all influence search of the fastest (the shortest in time) routes in the city (the system operates region-wide).

To find the shortest in respect of time (the fastest) rout one essential addition to the GIS-TMC system would be enough: a dynamic (automatically updated in real time) *street passing duration base* should be created.

Unfortunately, support of *street passing duration base* is impossible without creation of transport monitoring system operating in real time and consisting of sensor network, data collection communications system and data procession system.

Task definition

To describe city infrastructure **M** graph and matrix forms are used often.

$$\mathbf{M} = < \mathbf{S}, \mathbf{G} > . \qquad (1)$$

Here $\mathbf{S} = \{S_i\}$ – the set of crossroads; $\mathbf{G} = \{\boldsymbol{G}_{ij}\}$ – the set of streets.

Each street is characterized by the set

$$\boldsymbol{G}_{ij}(t) = < l_{ij} , \pi_{ij}(x) , v_{ij}(t) , n_{ij}(t) > \qquad (2)$$

Here l_{ij} – length of street $\boldsymbol{G}_{ij}$ [m];

$\pi_{ij}(x)$ – vertical profile function of street $\boldsymbol{G}_{ij}$ (slope/rise, depending on distance x);

$v_{ij}(t)$ – average speed of a vehicle [m/s] on the street $\boldsymbol{G}_{ij}$ at the moment of time t (t – time of the day);

$n_{ij}(t)$ – traffic density [number of vehicles per hour] on the street $\boldsymbol{G}_{ij}$ at the moment of time t;

If a city street network is described in the form of a graph, the search for *the fastest* (the *shortest in respect of time*) *route* comes down to the solution of a task to find the shortest path on the graphs.

The task to find the fastest (the shortest in respect of time) route (between points A and B) may be described as follows:

To find a consequence of crossroads indices between points A and B $\boldsymbol{K}$: $A \to S_\alpha \to S_\beta \to \ldots \to B$, where

$$\sum_{i,j,k\in K} \tau_{ij} \to \min. \qquad (3)$$

under the following conditions:

1) $\boldsymbol{G}_{A\alpha}$ exists (any special symbol may be a sign of non-existing in the total of streets $\mathbf{G} = \{\boldsymbol{G}_{ij}\}$);
2) $\boldsymbol{G}_{\alpha\beta}$ exists;
3) and so on up to the top B of the graph.

In this formula τ_{ij} is passing time of street $\boldsymbol{G}_{ij}$ except the time needed to pass the first street‘s crossroad.

Tasks to find the shortest rout on a graph are easily solved using well known Ford-Fulkerson, Bellman-Ford or similar algorithms [4].

It should be noted that a crossroad may be identified with a crossing. This means that $\boldsymbol{G}_{ij}$ is not necessarily from a crossroad to the nearest crossroad.

Street passing time τ_{ij} depends not only on the constant parameters of a street (length l_{ij}, number of crossroads or crossings h_{ij}, effective duration of red and green traffic light signals T_{raud} and T_{zal}), but also on the variable characteristics as well: average speed of vehicles $v_{ij}(t)$ and traffic density $n_{ij}(t)$ in it.

Passing time of street and its crossings (crossroads)

The street $\boldsymbol{G}_{ij}$, which length is l_{ij}, is passed on the average during the time τ_{ij} consisting of 4 parts:

1) τ_{ij}^{0} - time necessary to cover the distance l_{ij} driving at the speed $v_{ij}(t)$;

2) τ_{ij}^{sta} - time wasted braking at the restrictive signals of the traffic lights;

3) τ_{ij}^{st} - time wasted standing by the restrictive signals of the traffic lights;

4) τ_{ij}^{gr} - time wasted to accelerate after standing to the speed $v_{ij}(t)$:

$$\tau_{ij} = \tau_{ij}^{0} + \tau_{ij}^{sta} + \tau_{ij}^{st} + \tau_{ij}^{gr} . \qquad (4)$$

$$\tau_{ij}^{0} = \frac{l_{ij}}{v_{ij}(t)} . \qquad (5)$$

The bibliography of researching time τ_{ij}^{st} wasted standing by restrictive traffic light signals is rather rich. A lot of models have been offered (review can be found in [5]), but the problem of their selection still remains.

A uniform methodology of predicting street passing time τ_{ij} including τ_{ij}^{st} is created in this article.

The time τ_{ij}^{st} wasted standing by restrictive traffic light signal consists of two parts:

1) time of standing by the red signal τ_{ij}^{st-r} (from stop to lighting of permissive (green) signal);

2) time τ_{ij}^{st-p} of starting after the permissive (green) signal appears:

Thus,

$$\tau_{ij}^{st} = \tau_{ij}^{st-r} + \tau_{ij}^{st-p} . \qquad (6)$$

Average time of standing by the red light:

$$M\left\lfloor \tau_{ij}^{st-r} \right\rfloor = \frac{T_{raud}^{2}}{2(T_{zal} + T_{raud})} . \qquad (7)$$

If traffic density is $n_{ij}(t)$, then the number of vehicles standing in front of the road user waiting for the green traffic light signal will be $n_{ij}(t)\left(T_{raud} - \tau_{ij}^{st-r}\right)$. This means that the start after the green traffic light signal appears will be longer by $\tau_{ij}^{st-p} = \tau_r\, n_{ij}(t)\left(T_{raud} - \tau_{ij}^{st-r}\right)$ seconds.

Here τ_r – time of the driver‘s reaction (to starting of a vehicles standing in front of him).

The average value of this time is

$$M\left\lfloor \tau_{ij}^{st-p} \right\rfloor = \tau_r\, n_{ij}(t)\left(T_{raud} - M\left\lfloor \tau_{ij}^{st-r} \right\rfloor\right) =$$

$$= \tau_r\, n_{ij}(t)\left(\frac{T_{zal}T_{raud}}{T_{zal} + T_{raud}} + \frac{T_{raud}^{2}}{2\left(T_{zal} + T_{raud}\right)}\right) . \qquad (8)$$

It should be noted that often one has to stop even by the permissive (green) signal. This happens when one has to „catch up with“ the row formed at the crossroad which has not yet all started as the green signal appeared (because of the reason that the driver of the last vehicle reacts to the start of the first vehicle with bigger of smaller delay).

The time T_{st-z} from appearance of a green signal till acceleration of the vehicle which was the last in the row is expressed by the formula

$$T_{st-z} = \tau_r \; n_{ij}(t) \; T_{raud} \, . \tag{9}$$

A certain road user who „catch up with“ the row as the traffic light signal was already green has to wait for τ_{ij}^{st-z} seconds. Average time of waiting τ_{ij}^{st-z} is calculated by a formula similar to the formula (9):

$$M\left\lfloor \tau_{ij}^{st-z} \right\rfloor = = \frac{\left(T_{st-z}\right)^2}{2(T_{zal} + T_{raud})} = \frac{\left(\tau_r n_{ij}(t)\right)^2 T_{raud}^2}{2(T_{zal} + T_{raud})} \, . \tag{10 }$$

Time wasted for breaking and accelerating is calculated on the basis of the following assumptions:

1) breaking and start accelerations are considered to be equal and depend of the technical features of the vehicle. These accelerations for different vehicles under the city conditions may differ from 2 m/s^2 to 4 m/s^2. The accepted average is a = 3 m/s^2 ;

2) Breaking and acceleration modes (by one restrictive traffic light signal) last:

$$\tau^{st} = \tau^{gr} = \frac{v_{ij}(t)}{a} = \tau^{sg} \, . \tag{11}$$

3) a vehicle in breaking and acceleration mode at one restrictive traffic light signal moves:

$$l^{st} = l^{gr} = \frac{a\left(\tau^{st}\right)^2}{2} = \frac{a\left(\tau^{gr}\right)^2}{2} = \frac{a\left(\tau^{sg}\right)^2}{2} = l^{sg} \, . \tag{12}$$

In the cases when traffic lights of the street $\boldsymbol{G}_{ij}$ operate independently, and their number is h_{ij} , average passing duration of this street (from the first tot he last crossroad) is:

$$M\left\lfloor \tau_{ij}^{h_{ij}} \right\rfloor = \sum_{k=1}^{h_{ij}} \left\{ \begin{aligned} & \left(1 - \frac{\left(1 + \tau_r n_{ij-k}(t)\right) T_{raud}}{T_{zal} + T_{raud}}\right) \frac{l_{ij-k}}{v_{ij-k}(t)} + \\ & + \frac{2\left(1 + \tau_r n_{ij-k}(t)\right) T_{raud}}{T_{zal} + T_{raud}} \times \frac{v_{ij-k}(t)}{a} + \\ & + \tau_r n_{ij-k}(t) \frac{T_{zal} T_{raud}}{T_{zal} + T_{raud}} + \\ & + \frac{\left(1 + \tau_r n_{ij-k}(t) + \left(\tau_r n_{ij-k}(t)\right)^2\right) T_{raud}^2}{2\left(T_{zal} + T_{raud}\right)} + \\ & + \frac{\left(1 + \tau_r n_{ij-k}(t)\right) T_{raud}}{T_{zal} + T_{raud}} \times \frac{l_{ij-k} - 2l^{sg}}{v_{ij-k}(t)} \end{aligned} \right\} . \tag{13}$$

If traffic densities $n_{ij-k}(t)$ on all the sections of the street $\boldsymbol{G}_{ij}$ are the same, i.e. when $\forall k: \; n_{ij-k}(t) = n_{ij}(t)$, and flow speeds $\forall k: \; v_{ij-k}(t) = v_{ij}(t)$, average passing time of this street (from the first to the last crossroad) is

$$\begin{aligned} M\left\lfloor \tau_{ij}^{h_{ij}} \right\rfloor = & \left(1 - \frac{\left(1 + \tau_r n_{ij}(t)\right) T_{raud}}{T_{zal} + T_{raud}}\right) \frac{l_{ij}}{v_{ij}(t)} + \\ & + \frac{\left(1 + \tau_r n_{ij}(t)\right) T_{raud}}{T_{zal} + T_{raud}} \left\{2h_{ij} \frac{v_{ij}(t)}{a}\right\} + \tau_r n_{ij}(t) \; \frac{h_{ij} T_{zal} T_{raud}}{T_{zal} + T_{raud}} + \\ & + \frac{h_{ij}\left(1 + \tau_r n_{ij}(t) + \left(\tau_r n_{ij}(t)\right)^2\right) T_{raud}^2}{2\left(T_{zal} + T_{raud}\right)} + \\ & + \frac{\left(1 + \tau_r n_{ij}(t)\right) T_{raud}}{T_{zal} + T_{raud}} \; \frac{l_{ij} - 2h_{ij} l^{sg}}{v_{ij}(t)} \, . \end{aligned} \tag{14}$$

Dispersion of this time

$$D\left\lfloor \tau_{ij}^{h_{ij}} \right\rfloor = \frac{h_{ij}\left(T_{raud}\right)^3}{12\left(T_{zal} + T_{raud}\right)} \left[1 + 2\left(\tau_r n_{ij}(t)\right)^2\right] . \tag{15}$$

In formulas (13)-(15) most variables (l_{ij} , h_{ij} , T_{raud} , T_{zal}) are parameters of the street $\boldsymbol{G}_{ij}$ or traffic lights. Only two variables are functions of time: they are average speed of vehicles $v_{ij}(t)$ and traffic density $n_{ij}(t)$. Therefore, only these two variables should be constantly (in real time) updated and this is possible only with operating system of average speed and traffic density monitoring.

Unfortunately, principles of measuring average speed of a vehicles $v_{ij}(t)$ and traffic density $n_{ij}(t)$ differ significantly. Installation and service of monitoring systems for both these variables are expensive.

Analysis of analytic dependencies presented above showed that impact of one of these variables – traffic density - to street passing time in the calculation is less significant than that of the other – average speed $v_{ij}(t)$.

This means that in the average street passing time calculation formulas (13)-(15) instead of actual $n_{ij}(t)$ value could be used n_{ij} = 0,3 without a major loss of calculation accuracy. If we accept that n_{ij} = 0,3 and $\tau_r = 0{,}5$ [6] formulas (14), (15) acquire a simpler form:

$$\begin{aligned} M\left\lfloor \tau_{ij}^{h_{ij}} \right\rfloor = & \left(1 - \frac{1{,}15 T_{raud}}{T_{zal} + T_{raud}}\right) \frac{l_{ij}}{v_{ij}(t)} + \frac{2{,}3 h_{ij} T_{raud}}{T_{zal} + T_{raud}} \left\{\frac{v_{ij}(t)}{a}\right\} + \\ & + 0{,}15 \, h_{ij} \frac{T_{zal} T_{raud}}{T_{zal} + T_{raud}} + \frac{1{,}17 h_{ij} T_{raud}^2}{2\left(T_{zal} + T_{raud}\right)} + \\ & + \frac{1{,}15 T_{raud}}{T_{zal} + T_{raud}} \; \frac{l_{ij} - 2h_{ij} l^{sg}}{v_{ij}(t)} \, . \end{aligned} \tag{16}$$

$$D\left\lfloor \tau_{ij}^{h_{ij}} \right\rfloor = 0{,}8708 \frac{h_{ij}\left(T_{raud}\right)^3}{\left(T_{zal} + T_{raud}\right)} \, . \tag{17}$$

Calculations show that such simplification of formulas (using formula (16) instead of formula (14)) may bring errors comparable to standard deviation $D\left\lfloor \tau_{ij}^{h_{ij}} \right\rfloor$ of evaluation of average street passing time.

Conclusions

1. Traffic jams problem in the cities could be relieved by installation of information systems showing to road users in real time the fastest (the shortest in respect of passing time) routes. Such systems need dynamic *street passing durations base* for functioning which is possible only after creation of an automatic city transport monitoring system operating in real time and consisting of a network of sensors, a data collection communications system and a data processing system.

2. To evaluate a street passing duration it would be enough to measure average speed of vehicles in its characteristic parts (sections between neighbouring crossings, crossroads, etc.) and the time wasted by restrictive signals could be evaluated by analytic calculations.

3. To find an optimal route it is possible to use classical search algorithms of the shortest (in accordance with a chosen criterion) way on the graphs.

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A problem is analyzed of further development of geographic informational systems with traffic monitoring channel (GIS-TMC) in order to present to the road users effective information about the fastest (the shortest in respect of time) routes and thus to improve use of existing city transport infrastructure. To solve this task it is suggested to create dynamic (automatically updated in real time) *street passing durations base,* for support of which a city transport monitoring system operating in real time is necessary consisting of a network of sensors, a data collection communications system and a data processing system. It is shown that to predict a street passing duration it is enough to measure speed of transport in the characteristic points of the street. Measurements of traffic density do not significantly improve accuracy of forecast of a street passing time. Analytical formulas are presented meant to forecast a street passing time. Ill. 1, bibl. 6 (in English; summaries in English, Russian, Lithuanian)

И. Даунорас, В. Багдонас, В. Гаргасас. Система для поиска оптимальных транспортных маршрутов // Электроника и электротехника. – Каунас: Технология, 2008 – № 3(83). – С. 63–66.

Представлены результаты исследования проблемы развития географических информационных систем с каналами контроля движения транспорта (ГИС-ТМЦ). Целью такого развития является обеспечение водителей оперативными данными о быстрейших (кратчайших по времени) маршрутах и заодно улучшение показателей использования фактической (с учетом временных преград и препятствий) пропускной способности инфраструктуры городского транспорта. Для решения данной задачи предлагается создание динамичной (возобновляемой в реальном времени) базы времен проезда улиц, для функционирования которой необходима система мониторинга движения городского транспорта, состоящая из системы датчиков, коммуникационной сети сбора данных и системы обработки данных. Показано, что для достаточно точного прогнозирования времени проезда улицы достаточно иметь данные о скорости транспортного потока в характерных точках вдоль трасы. Измерения интенсивности транспортного потока на точность прогнозы времени проезда улицы ощутимого влияния не имеют. Представлены формулы прогнозирования времени проезда улицы. Ил. 1, библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.)

J. Daunoras, V. Bagdonas, V. Gargasas. Optimalių transporto maršrutų paieškos sistema // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. –Nr. 3(83). – P. 63–66.

Nagrinėjama geografinių informacinių sistemų su eismo kontrolės kanalu (GIS-TMC) tolesnio tobulinimo problema, siekiant eismo dalyviams pateikti operatyvią informaciją apie greičiausius (trumpiausio laiko) maršrutus ir kartu pagerinti esamos miestų transporto infrastruktūros naudojimą. Šiam uždaviniui spręsti siūloma sukurti dinamišką (realiuoju laiku automatiškai atnaujinamą) *gatvių pervažiavimo trukmių bazę*, kuriai palaikyti reikalinga realiuoju laiku veikianti miesto transporto stebėsenos sistema, susidedanti iš jutiklių tinko, duomenų surinkimo komunikacijų sistemos ir duomenų apdorojimo sistemos. Parodyta, kad gatvės pervažiavimo trukmei prognozuoti pakanka transporto srauto greičio matavimu būdinguose gatvės taškuose. Srauto intensyvumo matavimai gatvės pervažiavimo laiko prognozės tikslumo labai nepadidina. Pateiktos analitinės formulės, skirtos gatvės pervažiavimo trukmei prognozuoti. Il. 1, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).