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CITY TRANSPORT MONITORING AND ROUTES OPTIMAL MANAGEMENT SYSTEM

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Abstract. The article analyses the problem of further development of geographic informational systems with traffic monitoring channel (GIS-TMC) in order to present the road users with effective information about the fastest (the shortest in respect of time) routes and thus to improve the use of existing city transport infrastructure. To solve this task it is suggested to create dynamic (automatically updated in real time) *street passing duration 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. In the article it is shown that to predict the 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 forecasting the street passing time. Analytical formulas are presented meant to forecast the street passing time.

Keywords: city transport, fastest route, monitoring system, street passing duration, forecast.

1. Introduction

Rise in the number of cars increases environmental pollution and number of accidents, 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 environmental pollution.

The research has shown that external costs related to traffic jams on the roads reach up to 0,5 % EU GDP, i.e. about 56 bill. EUR (European Transport … 2001). In 2010 this sum may rise up to 80 bill. EUR. For Lithuania these losses could reach 350 mill. litas.

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 analyses the second possibility to partially solve the traffic jams problem.

Nowadays Geographic Information System (GIS) is available to every road user and the range of such services is constantly developing and improving (Car Navigation… 2007; Brenner and Elias 2003; Kealy and Scott-Young 2006). At present the most universal are *GIS-TMC systems* (*navigation systems* with *TMC Traffic Message Channel*). The structural diagram of such system is shown in Fig. 1.

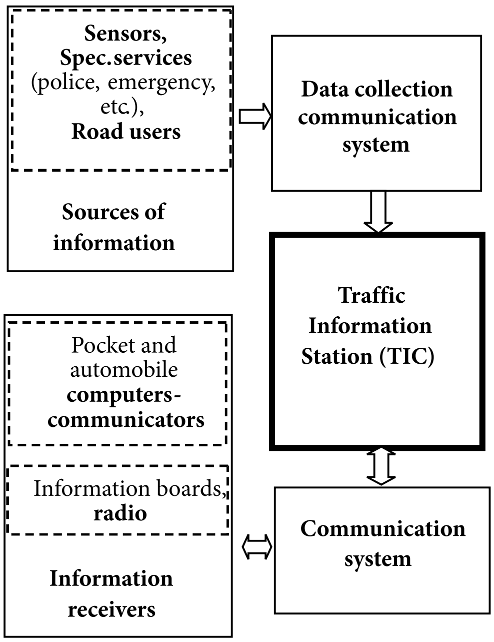

Fig. 1. Structural diagram of GIS-TMC system

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:

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- 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, 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).

The system's 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 the search for the fastest (the shortest in time) routes in the city (the system operates region-wide).

Balsys *et al.* (2007) assert – fast improvement of computers, automation systems, communications, mechatronic means allow *Intellectual Transport Control Systems* (ITCS) 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,* etc.) route in the current situation.

To find the shortest in respect of time (the fastest) route, 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 a sensor network, a data collection communications system and a data processing system.

Street passing duration time could be measured by the following methods:

- directly, i.e. measuring the time spent by the car for passing this street;
- measuring the speed of vehicles on the typical parts of the street (for example, between two nearest traffic lights).

Both these methods are realized by similar technical means, however they are not equally effective.

Advantage of the first method: a little simpler monitoring system. Drawbacks:

- information delay in time equal to the street passing time;
- uncertainty of the result: it is not clear if the vehicle drove non-stop, if it stopped at the traffic light and if so, how much time it stood.

The second method does not have these drawbacks. Therefore further all attention will be paid only to it.

2. Task definition

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

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

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

Each ***crossroad*** S_i is characterized by its *passing time matrix* $\|\tau_{ji-ik}(t)\|$. In this matrix j and k are indices of crossroads (S_j and S_k) connected with crossroad S_i by streets $\boldsymbol{G}_{ji}$ and $\boldsymbol{G}_{ik}$.

$\tau_{ji-ik}(t)$ is the time vehicle stands at crossroad S_i before it enters street $\boldsymbol{G}_{ik}$. from street $\boldsymbol{G}_{ji}$.

If a crossroad is not a roundabout, one of the most important parameters of its operation is duration of traffic light working cycle and duration of separate phases.

In this article only effective duration of green and red traffic lights phases (T_{zal} and T_{raud}) is described. It is assumed that during other phases a vehicle either stands by the traffic light or passes it. Therefore duration of traffic light intermediate phases is conditionally "distributed" between the main phases.

Each ***street*** is characterized by the set:

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

where 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; $h_{ij}(t)$ – average number of stops at crossroads or crossings controlled by traffic lights (it is assumed that there are no other crossings) at the moment of time t; $a_{ij}(t)$ – accident risk index 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*:

$$\boldsymbol{K}:\ A \rightarrow S_\alpha \rightarrow S_\beta \rightarrow \ldots \rightarrow B,$$

where

$$\sum_{i,j,k\in K}\left(\tau_{ij} + \tau_{ij-jk}\right) \rightarrow \min \quad (3)$$

under the following conditions:

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

In this formula τ_{ij} is passing time on street $\boldsymbol{G}_{ij}$ except the time needed to pass the first street's crossroads evaluated by $\tau_{ij-jk}(t)$.

Tasks to find the shortest route on a graph are easily solved using well known Ford-Fulkerson, Bellman-Ford or similar algorithms, see investigations of Agarwal and Sharir (1998).

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

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

3. Passing time of street and its crossings (crossroads)

The street $\boldsymbol{G}_{ij}$, which length is l_{ij}, is passed on 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 at the restrictive signals of the traffic lights;
4) τ_{ij}^{gr} – time wasted to accelerate after standing to the speed $v_{ij}(t)$:

$$\tau_{ij} = \tau_{ij}^{0} + \tau_{ij}^{sta} + \tau_{ij}^{st} + \tau_{ij}^{gr}, \tag{4}$$

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

The bibliography of researching time τ_{ij}^{st} wasted standing at restrictive traffic light signals is rather rich. A lot of models have been offered (review can be found in research by Rouphail, Tarko and Li 1996), 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 at restrictive traffic light signals consists of two parts:

1) time of standing at 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,

$$\tau_{ij}^{st} = \tau_{ij}^{st-r} + \tau_{ij}^{st-p}. \tag{6}$$

Average time of standing at the red light:

$$M\left[\tau_{ij}^{st-r}\right] = \int_{0}^{T_{raud}} \tau_{ij}^{st-r} P_{sta} \rho_{sta}\left(\tau_{ij}^{st-r}\right) d\tau_{ij}^{st-r}. \tag{7}$$

where: $P_{sta} = \dfrac{T_{raud}}{T_{zal} + T_{raud}}$ means probability that one will have to stop at the red traffic light signal; $\rho_{sta}(\tau_{ij}^{st-r}) = 1/T_{raud}$ – conditional probability that after having stopped at the red traffic light signal one will have to wait for the green signal for the time $\tau_{ij}^{st-r} \in [0, T_{raud}]$; density function (it acquires such a form for the reason that the time of waiting at the red traffic light signal is distributed equally during the time interval $[0, T_{raud}]$).

After insertion of certain probability expressions it is received:

$$M\left[\tau_{ij}^{st-r}\right] = P_{sta} \int_{0}^{T_{raud}} \frac{\tau_{ij}^{st-r}}{T_{raud}} d\tau_{ij}^{st-r} = \frac{T_{raud}^{2}}{2(T_{zal} + T_{raud})}. \tag{8}$$

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 $n_{ij}(t)\,(T_{raud} - \tau_{ij}^{st-r})$. This means that the start after the green traffic light signal appears will be longer by $\tau_{ij}^{st-p} = \tau_r\, n_{ij}(t)(T_{raud} - \tau_{ij}^{st-r})$ seconds, where τ_r – time of the driver's reaction (to starting of vehicles standing in front of him).

The average value of this time is:

$$M\left[\tau_{ij}^{st-p}\right] = \tau_r n_{ij}(t)\left(T_{raud} - M\left[\tau_{ij}^{st-r}\right]\right) =$$
$$\tau_r n_{ij}(t)\left(\frac{T_{zal}T_{raud}}{T_{zal} + T_{raud}} + \frac{T_{raud}^{2}}{2\left(T_{zal} + T_{raud}\right)}\right). \tag{9}$$

Thus, the average time wasted standing at the restrictive traffic light signal is:

$$M\left[\tau_{ij}^{st}\right] = M\left[\tau_{ij}^{st-r}\right] + M\left[\tau_{ij}^{st-p}\right] =$$
$$\tau_r n_{ij}(t)\frac{T_{zal}T_{raud}}{T_{zal} + T_{raud}} +$$
$$\left(1 + \tau_r n_{ij}(t)\right)\frac{T_{raud}^{2}}{2(T_{zal} + T_{raud})}. \tag{10}$$

It should be noted that often one has to stop even at the permissive (green) signal. This happens when one has to "catch up with" the row formed at the crossroads which has not yet all started as the green signal appeared (for 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:

$$T_{st-z} = \tau_r n_{ij}(t) T_{raud} + \tau_{ij}^{gr}. \tag{11}$$

Further to make it easier, the time of acceleration of the last vehicle in the row τ_{ij}^{gr} may not be evaluated because, as the last vehicle in the row starts away, the vehicles following it have only to break (and not to stop fully).

Thus,

$$T_{st-z} = \tau_r n_{ij}(t) T_{raud}. \tag{12}$$

A certain road user who wanted to "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 (8):

$$M\left[\tau_{ij}^{st-z}\right]=P_{st-z}\int_0^{T_{st-z}}\frac{\tau}{T_{st-z}}d\tau=$$

$$\frac{\left(T_{st-z}\right)^2}{2(T_{zal}+T_{raud})}=\frac{\left(\tau_r n_{ij}(t)\right)^2T_{raud}^2}{2(T_{zal}+T_{raud})}. \quad (13)$$

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

- Braking and start of acceleration are considered to be equal and depend on 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 .
- Braking and acceleration modes (at one restrictive traffic light signal) last:

$$\tau^{st}=\tau^{gr}=\frac{v_{ij}(t)}{a}=\tau^{sg}. \quad (14)$$

- A vehicle in braking and acceleration mode at one restrictive traffic light signal moves:

$$l^{st}=l^{gr}=\frac{a\left(\tau^{st}\right)^2}{2}=\frac{a\left(\tau^{gr}\right)^2}{2}=\frac{a\left(\tau^{sg}\right)^2}{2}=l^{sg}. \quad (15)$$

It should be noted that probability of braking-acceleration procedure is $P_{sta}=\dfrac{T_{raud}+T_{st-z}}{T_{zal}+T_{raud}}$.

Or, evaluated (12),

$$P_{sta}=\frac{\left(1+\tau_r n_{ij}(t)\right)T_{raud}}{T_{zal}+T_{raud}}. \quad (16)$$

Thus, if traffic lights of the street $\boldsymbol{G}_{ij}$ are tuned in the "green wave" mode, average passing duration of this street (from the first to the last crossroads) is:

$$M\left[\tau_{ij}^{1}\right]=(1-P_{sta})\tau_{ij}^{0}+P_{sta}\left[\tau_{ij}^{sta}+\tau_{ij}^{gr}\right]+$$
$$M\left[\tau_{ij}^{st}\right]+M\left[\tau_{ij}^{st-z}\right]+P_{sta}\left[\frac{l_{ij}-2l^{sg}}{v_{ij}(t)}\right]=$$
$$\left(1-\frac{\left(1+\tau_r n_{ij}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\right)\frac{l_{ij}}{v_{ij}^{\max}}+$$
$$\frac{\left(1+\tau_r n_{ij}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\left\{2\frac{v_{ij}(t)}{a}\right\}+$$
$$\tau_r n_{ij}(t)\frac{T_{zal}T_{raud}}{T_{zal}+T_{raud}}+$$
$$\frac{\left(1+\tau_r n_{ij}(t)+\left(\tau_r n_{ij}(t)\right)^2\right)T_{raud}^2}{2\left(T_{zal}+T_{raud}\right)}+$$
$$\frac{\left(1+\tau_r n_{ij}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\frac{l_{ij}-2l^{sg}}{v_{ij}(t)}. \quad (17)$$

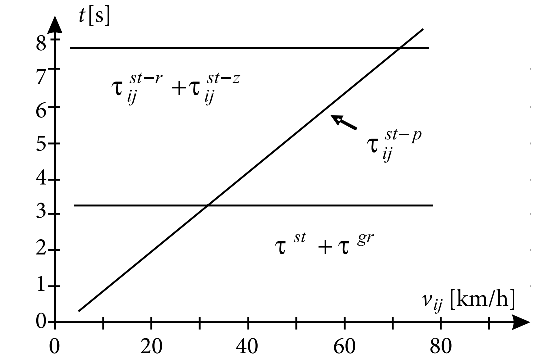

Fig. 2. Dependence of different components of disturbing impact of the traffic lights and the speed of flow, when $n_{ij}(t)$ = 0.3 [1/s]

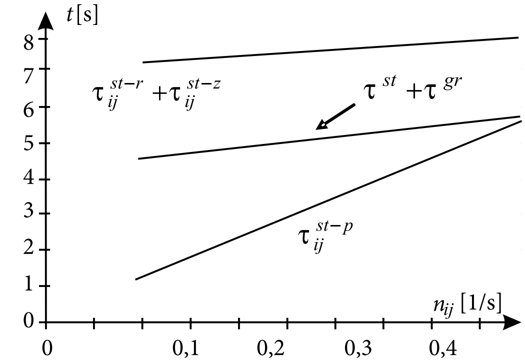

Fig. 3. Dependence of different components of disturbing impact of the traffic lights and flow density, when $v_{ij}(t)$ = 50 [km/h]

Influence of different components of disturbing impact of the traffic lights is not the same (Figs. 2, 3).

In the cases when traffic lights of the street $\boldsymbol{G}_{ij}$ operate independently, and their number is h_{ij},

$$M\left[\tau_{ij}^{h_{ij}}\right]=\sum_{k=1}^{h_{ij}}\left\{\begin{aligned}&\left(1-\frac{\left(1+\tau_r n_{ij-k}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\right)\frac{l_{ij-k}}{v_{ij-k}(t)}+\\&\frac{2\left(1+\tau_r n_{ij-k}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\times\frac{v_{ij-k}(t)}{a}+\\&\tau_r n_{ij-k}(t)\frac{T_{zal}T_{raud}}{T_{zal}+T_{raud}}+\\&\frac{\left(1+\tau_r n_{ij-k}(t)+\left(\tau_r n_{ij-k}(t)\right)^2\right)T_{raud}^2}{2\left(T_{zal}+T_{raud}\right)}+\\&\frac{\left(1+\tau_r n_{ij-k}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\times\frac{l_{ij-k}-2l^{sg}}{v_{ij-k}(t)}\end{aligned}\right\}. \quad (18)$$

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 crossroads) is:

$$M\left[\tau_{ij}^{h_{ij}}\right]=\left(1-\frac{\left(1+\tau_r n_{ij}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\right)\frac{l_{ij}}{v_{ij}(t)}+$$
$$\frac{\left(1+\tau_r n_{ij}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\left\{2h_{ij}\frac{v_{ij}(t)}{a}\right\}+$$
$$\tau_r n_{ij}(t)\frac{h_{ij}T_{zal}T_{raud}}{T_{zal}+T_{raud}}+$$
$$\frac{h_{ij}\left(1+\tau_r n_{ij}(t)+\left(\tau_r n_{ij}(t)\right)^2\right)T_{raud}^2}{2\left(T_{zal}+T_{raud}\right)}+$$
$$\frac{\left(1+\tau_r n_{ij}(t)\right)T_{raud}}{T_{zal}+T_{raud}}\cdot\frac{l_{ij}-2h_{ij}l^{sg}}{v_{ij}(t)}. \quad (19)$$

Dispersion of this time:

$$D\left[\tau_{ij}^{h_{ij}}\right]=\frac{h_{ij}\left(T_{raud}\right)^3}{12\left(T_{zal}+T_{raud}\right)}\left[1+2\left(\tau_r n_{ij}(t)\right)^2\right]. \quad (20)$$

In formulas (17)–(19) 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: 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 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 – on street passing time in the calculation is less significant than that of the other – average speed of vehicles $v_{ij}(t)$.

In formulas (17)–(19) traffic density $n_{ij}(t)$ is multiplied by the average time of reaction of a vehicle waiting in a row to the start of the previous vehicle τ_r. The latter value is forecasted rather inaccurately. This results in the increase of uncertainty of impact of traffic density $n_{ij}(t)$.

Rather a wide time range of a driver's reaction to the start of the previous vehicle are investigated by Green (2000); Mcgehee *et al.* (2000); Ma and Andréasson (2006). Depending on the individual features of a driver and environment, this time is within the limits of 0.2 s – 1.5 s. For the primary analysis of the formulas (17)–(19) it is accepted that $\tau_r = 0.5$ s.

Calculations (using formulas (17) and (19)) show that standard deviation from the result of calculations of an average passing time for the street $\boldsymbol{G}_{ij}$, the length of which is 1.5 km and where "green wave" mode is realized (it is accepted that there is only one traffic light with a cycle $T_{zal} = T_{raud} = 30$ s), $M[\tau_{ij}^1]$ is from 6.1 s to 6.5 s. And this is two times more than correction of approximate result of calculation of an average street passing time $M[\tau_{ij}^1]$ (obtained accepting that traffic density is average and equals $n_{ij} = 0.3$) obtained after evaluation of the result of measuring traffic density n_{ij}. In fact, calculations show that $M[\tau_{ij}^1]$ calculation result obtained accepting that traffic density is average ($n_{ij} = 0.3$) and $M[\tau_{ij}^1]$ calculation result received using data of traffic density measurements (when traffic density changes within the range from 0.1 (aut./s) to 0.5 (aut./s)) shall differ in not more than 2.8 s.

If on the same street there would be 15 traffic lights operating independently one from another with the cycle of each of them $T_{zal} = T_{raud} = 30$ s, then standard deviation from calculation of average passing time $M[\tau_{ij}^{15}]$ would be between 21.8 s and 25.2 s, and correction of the result of approximate $M[\tau_{ij}^{15}]$ calculation (obtained accepting that traffic density is equal to $n_{ij} = 0.3$) obtained evaluating the result of measuring traffic density n_{ij} would be not more than 42 s.

This means that in the average street passing time calculation formulas (17)–(19) instead of actual $n_{ij}(t)$ value $n_{ij} = 0.3$ could be used without a major loss of calculation accuracy:

$$n_{ij}(t) \to n_{ij} = 0.3. \quad (21)$$

If we accept that $n_{ij} = 0.3$ and $\tau_r = 0.5$, formulas (17), (19), (20) acquire a simpler form: (see (22)–(24)):

$$M\left[\tau_{ij}^{1}\right]=\left(1-\frac{1.15T_{raud}}{T_{zal}+T_{raud}}\right)\frac{l_{ij}}{v_{ij}(t)}+$$
$$\frac{2.3T_{raud}}{T_{zal}+T_{raud}}\left\{\frac{v_{ij}(t)}{a}\right\}+$$
$$0.15\frac{T_{zal}T_{raud}}{T_{zal}+T_{raud}}+\frac{1.17T_{raud}^2}{2\left(T_{zal}+T_{raud}\right)}+$$
$$\frac{1.15T_{raud}}{T_{zal}+T_{raud}}\frac{l_{ij}-2l^{sg}}{v_{ij}(t)}; \quad (22)$$

$$M\left[\tau_{ij}^{h_{ij}}\right]=\left(1-\frac{1.15T_{raud}}{T_{zal}+T_{raud}}\right)\frac{l_{ij}}{v_{ij}(t)}+$$
$$\frac{2.3h_{ij}T_{raud}}{T_{zal}+T_{raud}}\left\{\frac{v_{ij}(t)}{a}\right\}+$$
$$0.15h_{ij}\frac{T_{zal}T_{raud}}{T_{zal}+T_{raud}}+\frac{1.17h_{ij}T_{raud}^2}{2\left(T_{zal}+T_{raud}\right)}+$$
$$\frac{1.15T_{raud}}{T_{zal}+T_{raud}}\frac{l_{ij}-2h_{ij}l^{sg}}{v_{ij}(t)}; \quad (23)$$

$$D\left[\tau_{ij}^{h_{ij}}\right]=0.8708\frac{h_{ij}\left(T_{raud}\right)^3}{\left(T_{zal}+T_{raud}\right)}. \quad (24)$$

Calculations show that such simplification of formulas (using formula (22) instead of formula (17) and formula (23) instead of formula (19)) may bring errors comparable to standard deviation from evaluation of average street passing time $M[\tau_{ij}^1]$ and $M[\tau_{ij}^{h_{ij}}]$ (errors are, correspondingly, 3.3 s and 49.3 s, standard deviation – 8.3 s and 32.3 s).

4. Conclusions

1. Traffic jam problems in the cities could be relieved by installation of information systems showing the road users in real time the fastest (the shortest in respect of passing time) routes. Such systems need dynamic *street passing duration 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 the 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 at the 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.
4. The suggested system could effectively function only after improvement of the existing Geographic Informational Navigation System (GINS): a possibility should be offered to road users to exchange information with central data processing and management station (receiving by request either optimal route data or data necessary to calculate the optimal route).

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