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

The street \( G_{ij} \), which length is \( l_{ij} \), is passed on the average during the time \( \tau_{ij} \) consisting of 4 parts:

1) \( \tau_{ij}^0 \) - time necessary to cover the distance \( l_{ij} \) driving at the speed \( v_{ij}(t) \);
2) \( \tau_{ij}^{sta} \) - time wasted braking at the restrictive signals of the traffic lights;
3) \( \tau_{ij}^{st} \) - time wasted standing by the restrictive signals of the traffic lights;
4) \( \tau_{ij}^{tr} \) - time wasted to accelerate after standing to the speed \( v_{ij}(t) \):

\[
\tau_{ij} = \tau_{ij}^0 + \tau_{ij}^{sta} + \tau_{ij}^{st} + \tau_{ij}^{tr}.
\]

\[
\tau_{ij}^0 = \frac{l_{ij}}{v_{ij}(t)}.
\]

The bibliography of researching time \( \tau_{ij}^{st} \) 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 \( \tau_{ij} \) including \( \tau_{ij}^{st} \) is created in this article.

The time \( \tau_{ij}^{tr} \) wasted standing by restrictive traffic light signal consists of two parts:

1) time of standing by the red signal \( \tau_{ij}^{fr} \) (from stop to lighting of permissive (green) signal);
2) time \( \tau_{ij}^{fr} \) of starting after the permissive (green) signal appears:

Thus,

\[
\tau_{ij}^{fr} = \tau_{ij}^{fr} + \tau_{ij}^{fr}.
\]

Average time of standing by the red light:

\[
M[\tau_{ij}^{fr}] = \frac{T_{rad}^2}{2(T_{rad} + T_{val})}.
\]

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 \( n_{ij}(t) \left( T_{rad} - \tau_{ij}^{fr} \right) \). This means that the start after the green traffic light signal appears will be longer by \( \tau_{ij}^{fr} = \tau_{ij} n_{ij}(t) \left( T_{rad} - \tau_{ij}^{fr} \right) \) seconds.

Here \( \tau_x \) - time of the driver’s reaction (to starting of a vehicles standing in front of him).

The average value of this time is

\[
M[\tau_{ij}^{fr}] = \tau_x n_{ij}(t) \left( T_{rad} - M[\tau_{ij}^{fr}] \right) = \tau_x n_{ij}(t) \left( \frac{T_{rad}^2}{2(T_{rad} + T_{val})} \right).
\]
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 $T_{st^{-}}$ from appearance of a green signal till acceleration of the vehicle which was the last in the row is expressed by the formula

$$T_{st^{-}} = r_{ij} n_{ij}(t) T_{raud}.$$  \hfill (9)

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

$$M[\tau_{ij}^{st^{-}}] = \frac{(T_{st^{-}})^2}{2(T_{col} + T_{raud})} = \left(\frac{r_{ij} n_{ij}(t)}{T_{col} + T_{raud}}\right)^2 \frac{\sigma^2_{T_{raud}}}{2(T_{col} + T_{raud})}.$$  \hfill (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/s² to 4 m/s². The accepted average is $a = 3$ m/s²;
2) Breaking and acceleration modes (by one restrictive traffic light signal) last:

$$\tau_{st} = \tau_{er} = \frac{v_{ij}(t)}{a} = \tau_{er}.$$  \hfill (11)

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

$$l_{st} = l_{er} = \frac{a \tau_{st}^2}{2} = \frac{a \tau_{er}^2}{2} = \frac{a \tau_{er}^2}{2} = l_{er}.$$  \hfill (12)

In the cases when traffic lights of the street $G_{ij}$ operate independently, and their number is $h_{ij}$, average passing duration of this street (from the first to the last crossroad) is:

$$M[\tau_{ij}] = \sum_{k=1}^{h_{ij}} \left\{ \frac{\left[ 1 + (1 + r_{ij} n_{ij-k}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij-k}(t)} + \frac{\left[ 1 + (1 + r_{ij} n_{ij-k}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{\frac{T_{col} T_{raud}}{T_{col} + T_{raud}}} + \frac{\left[ 1 + (1 + r_{ij} n_{ij-k}(t)) (1 + r_{ij} n_{ij-k}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{2(T_{col} + T_{raud})} + \frac{\left[ 1 + (1 + r_{ij} n_{ij-k}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij-k}} \right\}.$$  \hfill (13)

If traffic densities $n_{ij-k}(t)$ on all the sections of the street $G_{ij}$ 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

$$M[\tau_{ij}] = \left\{ \frac{1 - \frac{1 + (1 + r_{ij} n_{ij}(t)) T_{col} + T_{raud}}{v_{ij}(t)}}{T_{col} + T_{raud}} + \frac{\left[ 1 + (1 + r_{ij} n_{ij}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij}(t)} + \frac{\left[ 1 + (1 + r_{ij} n_{ij}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij}(t)} + \frac{\left[ 1 + (1 + r_{ij} n_{ij}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij}(t)} \right\}.$$  \hfill (14)

Dispersion of this time

$$D[\tau_{ij}] = \frac{h_{ij} T_{raud}^3}{12(T_{col} + T_{raud})} \left[ 1 + 2(r_{ij} n_{ij}(t))^2 \right].$$  \hfill (15)

In formulas (13)-(15) most variables ($l_{ij}$, $h_{ij}$, $T_{col}$, $T_{raud}$) are parameters of the street $G_{ij}$ 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 $r_{ij} = 0.5$ [6] formulas (14), (15) acquire a simpler form:

$$M[\tau_{ij}] = \left\{ \frac{1 - \frac{1 + (1 + r_{ij} n_{ij}(t)) T_{col} + T_{raud}}{v_{ij}(t)}}{T_{col} + T_{raud}} + \frac{\left[ 1 + (1 + r_{ij} n_{ij}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij}(t)} + \frac{\left[ 1 + (1 + r_{ij} n_{ij}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij}(t)} + \frac{\left[ 1 + (1 + r_{ij} n_{ij}(t)) \frac{T_{col} T_{raud}}{T_{col} + T_{raud}} \right]}{v_{ij}(t)} \right\}.$$  \hfill (16)

$$D[\tau_{ij}] = \frac{0.8708 h_{ij} T_{raud}^3}{(T_{col} + T_{raud})}.$$  \hfill (17)

Calculations show that such simplification of formulas (using formula (16) instead of formula (14)) may bring errors comparable to standard deviation $D[\tau_{ij}]$ of evaluation of average street passing time.
Conclusions

1. Traffic jams problem in the cities could be resolved 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.

References


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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)


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 динамической (возобновляемой в реальном времени) базы времени 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 трассы. 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.)


Нагrinejama geografinių informacinių sistemų su eismo kontrolės kanalu (GIS-TMC) tolesnio tobulinimo problema, siekiant eismo dalyviams pateikti operatyvią informaciją apie greičiausias (trumpiausias laiko) maršrutus ir kartu pagerinti esamos miestų transporto infrastruktūros naudojimą. Šiam uždaviniui spręsti sėlima sukurti dinamiką (realizuojantį automatišką atnaujinimą) gatvių pervažiavimo trakinių būcų, kuriai palaikyti reikalinga realizuojant galima veikianti miesto transporto stebėsenos sistema, susidedanti iš įvairių tūkst., duomenų surinkimo komunikacinių sistemų ir duomenų apdorojimo sistemų. Parodyta, kad gatvės pervažiavimo trukmei prognozuoti padėtų gatvių greičio matavimai būdinguose gatvės taškųose. Srauto intensyvumo matavimai gatvės pervažiavimo laiko prognozės tikslumo labai nepadidina. Pateikti analitinės formulės, skirtos gatvės pervažiavimo trukmei prognozuoti. Il. 1, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.)