APPLICATION OF THE MOBILE SATELLITE NAVIGATION SYSTEM TO STUDY THE MOVEMENT OF THE ROAD TRAIN

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Abstract: In the research is presented experiment of observation and analysis of the movement of means of transport in real time through the application of a system of satellite navigation. A method for controlling the movement of a vehicle with a mobile satellite navigation system is experimented with optimization of technical and operational parameters. A method is developed for defining the sections of the route by which to carry out optimization of transportation. In the research is proposed a conception of assessing energy efficiency of road train that can be used for optimal control of the movement of the vehicle depending on the strategy of the transport company.

KEYWORDS: ROAD TRAIN, GPS, FUEL CONSUMPTION, RELATIVE PERFORMANCE, TRANSPORT COMPANY

1. Introduction

The main part of the cost of transport companies is in the organization and implementation of transport logistics. The application of satellite navigation equipment allows an optimization and control of transport activity of each company. The aim is to reduce the fuel costs and unproductive downtime by applying the continuous monitoring of the situation and condition of the vehicles during transport.

Satellite navigation systems in transport are two types - mobile and global. First there are used to calculate the coordinates and calculate the route between points. As part of transport logistics, they serve to correct the route of the vehicle. Global systems collect information on all vehicles. This information can be used for operational management of the transport process and strategic planning to determine the routes through using a large amount of data: indicators for dimensions and mass of the load; number of points along the route; optimum speed; duration of downtime or cargo operations and etc.

Satellite monitoring in transport is a system for monitoring moving objects based entirely on the satellite navigation systems, network equipment and radio connection, computers and digital maps. It is used to solve many problems of transport logistics in the management of transportation and automated control systems of vehicles. The principle of operation is to obtain and analyze spatial and temporal coordinates of the vehicle. There are two types of monitoring:

- Online – remote transmission of information. Vehicle shall be equipped with a mobile device, which consists of the following elements - receiver of signals from satellites modules for storage and transmission of the coordinates of the object. The mobile device receives the coordinate data from the receiver of signals recorded them in the module for storing and transmits them by transmission module. The data obtained are analyzed and transmitted to dispatchers in text or graphic form.

The aim of this study is:

- To experiment observation and analyzing the movement of vehicles in real time through the application of satellite navigation system.
- To experiment methodology to determine traffic management of a road train on a route where the total cost of fuel for the different sections of the road are minimized depending on the specified technical and operational criterion.
- To develop a methodology for determining the number of sections in a route for which to experiment methodology for controlling the movement of vehicles.

2. Development of a functional system to evaluate the energy efficiency of a road train

Optimal management of the auto train movement is associated with reduced fuel consumption. For effective management of the movement of a road train on a route in [1] has developed a methodology that allows to minimize the total fuel costs for the individual sections of the road depending on the specified technical and operational criterion. For its practical realization as a system for assessment the energy efficiency of road train is necessary to apply

a refined communication GPS/GPRS system in road trains. This system should inform the drivers what is the optimal speed and gear of the gearbox of the tractor of the road train to achieve minimum fuel consumption at selected technical and operational optimization criterion in each section of the route.

The necessary data that must be obtained from an elaborate communication system for realizing the methodology are, fig.1:

- Coordinates and calculation of the route between points.
- Altitude.
- Speed limit on the route.
- Map of the route.

For optimal implementation of movement should be monitored in a control center. Through the GPS system can be monitored vehicle position, speed and altitude all over the route, and in the GPRS system to obtain information on fuel, gear included in the gearbox of the tractor, its engine load, speed a headwind, road deviations, speed and unplanned stop. These data can be used to adapt the processes and efficient transport activity in transport companies.

3. Mobile satellite system for monitoring

System for assessment the energy efficiency of vehicles including a auto train, includes the following components, Fig. 2:

- A means of transportation equipped with a satellite navigation system GPS.
- Dispatch Center.
- A computer of the operator of the transport company, which is monitored.
The means of transport through the satellite system receives data from the satellites and transmits them in real time in the centre (server) where the information is recorded. The centre has software for reception, storage, processing and analysis of information. The computer of the operator of the transport company receives and records information in real time.

The system can be monitored in real time the location of the vehicle, velocity of movement, road profile, the distance traveled, number of stops and their duration.

The following indexes shall be measured:
- Geographical coordinates.
- Speed of movement of the vehicle.
- Exactly time.

On the translation of geographical coordinates in decimal numbers must be taken into account:
- Depending on whether the source is latitude or longitude and according to the direction, the decimal coordinates may be positive or negative numbers.
- Conversion from degrees, minutes, seconds to decimal format is by adding degrees of minutes divided by 60, plus seconds divided by 3600. For example, if latitude is 42°37.981', the decimal equivalent is 42 + (37.981/60) = 42.6330. If the position was to the North, the sign will be positive, if it has been in the South, then the sign will be negative. [5].

The covered distance between two consecutive points i and (i + 1) of the route can be determined in the following ways, fig.3.:

\[ l_{ij} = \frac{(v_i + v_j) \cdot 0.5}{3600} \Delta t, \text{ km} \]  (3)

\[ \Delta t = (t_{i+1} - t_i), \text{ sek}, \]  (4)

where: \( l_{ij} \) is the road traveled between two consecutive points i and (i + 1) of the route determined according to speed and travel time, km; \( v_i, v_{i+1} \) are the speed of movement of the vehicle at the time i and (i + 1), km/h; \( \Delta t \) is the interval of time to travel the distance between points i and (i + 1), sec.

### 4. Method for forming sections of the route
Observations of the movement of the vehicle are formed in the form of a table (table 2), in which for every two consecutive sections of the route are recorded: length in km, altitude in m, speed restriction, km/h.

### Table 2. Formation of the sections

<table>
<thead>
<tr>
<th>Section</th>
<th>km</th>
<th>Altitude, m</th>
<th>Speed restriction ( v_{\text{max}} ), km/h</th>
<th>Index \ i</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( l_1 )</td>
<td>( h_1 )</td>
<td>( v_{\text{max}1} )</td>
<td>( i_1 )</td>
</tr>
<tr>
<td>2</td>
<td>( l_2 )</td>
<td>( h_2 )</td>
<td>( v_{\text{max}2} )</td>
<td>( i_2 )</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>( j )</td>
<td>( l_j )</td>
<td>( h_j )</td>
<td>( v_{\text{max}j} )</td>
<td>( i_j )</td>
</tr>
<tr>
<td>( j+1 )</td>
<td>( l_{j+1} )</td>
<td>( h_{j+1} )</td>
<td>( v_{\text{max}(j+1)} )</td>
<td>( i_{j+1} )</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>( n )</td>
<td>( l_n )</td>
<td>( h_n )</td>
<td>( v_{\text{max}} )</td>
<td>( i_n )</td>
</tr>
</tbody>
</table>

The main criteria for separating sections of the route by which to evaluate the energy efficiency of a train are:
- Maximum speed, km/h;
- Profile of the road.

The sections are formed taking into account the criteria in the following sequence:
1. Speed limit.
2. Profile of the road.

In the first stage of forming the sections is verified the condition:

\[ \gamma_{\text{max}}(j+1) \neq \gamma_{\text{max}}(j) \]  (5)

If this condition is satisfied is formed a section of the route. Successive sections with identical values of \( \gamma_{\text{max}} \) are merged.

In the second stage of the formation of sections for each segment is defined parameter i, characterizing the profile of the road.

\[ i = \frac{h_{i+1} - h_i}{(l_{i+1} - l_i)1000}, \]  (6)

where: \( h_{i+1} - h_i \) is the difference in altitude of two successive points of the route, m; \( l_{i+1} - l_i \) is the length of the section between points (i + 1) and i, km.

The sections are formed taking into account a change in road profile on the following conditions:

\[ i_j < 0 \text{ or } j_{j+1} > 0 \]  (7)
Conditions (7) indicate that section between two points is formed when changing road profile from positive to negative and vice versa.

Sections, which are located one after another in the acclivity (positive values of the parameter $i$) or downhill (negative values of the parameter $i$) are merged. It is assumed that the section is formed when the condition is met:

\[(8) \quad I_{i+1} - I_i \geq I, \]

where: $I$ is a parameter for the formation of a section. This parameter is set in advance, for example, $I = 0.1$, which corresponds to $5.7^\circ$ change in inclination; $I = 0.01$, which corresponds to $0.57^\circ$ change in inclination.

3. Length of the section

In the third step of forming the sections is taken into account to the condition determining the length of the section, which must be greater than a predefined value. Mobile satellite navigation systems reported in real time the distance between any two consecutive points of the route, depending on Geographical coordinates and altitude. Therefore, the number of sections depending on the length of the route is determined by the number of points of the route and is a very big number. Therefore, with the aim of reducing the number of sections and reduce the random influences of the way, it can be assumed that the section must be formed if it satisfies the condition:

\[(9) \quad l_{i+1} - l_i \geq L_{\text{min}}, \text{ km} \]

where: $L_{\text{min}}$ is a predetermined minimum length of the section, for example $L_{\text{min}} = 0.5\text{km}$.

Short and steep sections, as well as short sections in large inclines, give the variance in the data and this should be merged with the adjacent to the formation of a length corresponding to the condition of formula (9).

Figure 3 shows a graphic example of the stages of the formation of the sections.

The movement of the road train is presented as a network formed by sections of the route and variants of management in each area. For this purpose the route of movement of the road train is divided into separate sections according to the profile of the path. For each section are determined: maximum speed; potential traffic speeds in different gears.

It is necessary to determine traffic management of the road train on the route for which summary fuel costs to individual sections of road to be minimal, [1]. In each section of road fuel costs depend on the technical speed and resistance movement (road profile).

On Figure 4 is shown an example for graph for a route consisting of 4 sections and variations of 4 speeds of the vehicle, according to the method in [1].

5. Choice of effective number of sections of the route

When it is set different values of the parameters $I$ and $L_{\text{min}}$ can be formed a different number of sections on the same route. In a few areas could obtain variations in the results. The maximum number of the sections corresponds to the limiting values of both parameters and gives the most precise results but was associated with an increase in the computational procedures. The problem is to determine what is the rational number of sections.

To determine the effective number of sections were investigated following routes:

- **Sofia – Plovdiv (SF-PO)**
  - Variant 1: 4 sections
  - Variant 2: 11 sections

- **Plovdiv – Burgas (PO-BS)**
  - Variant 1: 18 sections
  - Variant 2: 26 sections

- **Sofia – Varna (SF-VA)**
  - Variant 1: 19 sections
  - Variant 2: 22 sections
  - Variant 3: 44 sections

- **Sofia – Dragoman (SF-DG)**
  - Variant 1: 8 sections
  - Variant 2: 16 sections
  - Variant 3: 47 sections

- **Sofia – Karlovo – Burgas (SF-KV-BS): 47 sections**
- **Varna – Burgas – Plovdiv (VA-BS-PO): 40 sections**
- **Varna – Burgas (VA-BS): 22 sections**

Table 3 shows the criteria that were formed sections ($I$, $L_{\text{min}}$ by formulas 8 and 9).

The observations of changes in road profile (altitude) were made with an interval of 10 meters.

In Table 3 variant 1 for the route Sofia - Plovdiv, Plovdiv - Burgas and Sofia - Varna is constituted by changes in road profile (ascent and downhill +/-). Routes Varna - Burgas, Sofia - Plovdiv is characterized by intensive change of road profile (+/-). The route Sofia - Varna additionally has frequent changes in maximum speed.

On fig.5, fig.6, fig.7 and fig.8 is made graphical representation of the road profile at a different number of sections for part of the route.
<table>
<thead>
<tr>
<th>Rout</th>
<th>Variant</th>
<th>Number of Notes</th>
<th>Number of Sections</th>
<th>I</th>
<th>Lmin, km</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF-KV-BS</td>
<td>345</td>
<td>47</td>
<td></td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>VA-BS</td>
<td>266</td>
<td>22</td>
<td></td>
<td>0.01</td>
<td>1.5</td>
</tr>
<tr>
<td>VA-BS-PO</td>
<td>483</td>
<td>40</td>
<td></td>
<td>0.001</td>
<td>2.5</td>
</tr>
<tr>
<td>SF-PO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Var.1</td>
<td>145</td>
<td>4</td>
<td>+/-</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Var.2</td>
<td>145</td>
<td>11</td>
<td>0.001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>PO-BS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Var.1</td>
<td>88</td>
<td>18</td>
<td>+/-</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Var.2</td>
<td>88</td>
<td>26</td>
<td>0.0001</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>SF-VA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Var.1</td>
<td>910</td>
<td>19</td>
<td>+/-</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Var.2</td>
<td>910</td>
<td>21</td>
<td>0.005</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Var.3</td>
<td>910</td>
<td>44</td>
<td>0.001</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>SF-DG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Var.1</td>
<td>84</td>
<td>8</td>
<td>0.01</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Var.2</td>
<td>84</td>
<td>16</td>
<td>0.01</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Var.3</td>
<td>84</td>
<td>47</td>
<td>0.001</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

To study the routes is applied the methodology of [1]. Optimization criterion is the minimum fuel efficiency (maximum performance). Table 4 compares the results (qL, 1 - fuel consumption). From fig.9 to fig.12 is shown a graphical comparison. On fig.13 shows the graph structure for the route Sofia - Dragoman, composed of 47 sections. On fig.14 shows the average length of a section for the investigated routes and variants.

**Fig.5. Sections of the route Sofia – Plovdiv**

**Fig.6. Sections of the route Plovdiv – Burgas**

**Fig.7. Sections of the route Sofia – Varna**

**Fig.8. Sections of the route Sofia - Dragoman**
Tab. 4. Comparison of variants

<table>
<thead>
<tr>
<th>Route</th>
<th>Variant</th>
<th>Number of section km</th>
<th>Function objective qL, l</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF-KV-BS</td>
<td>var. 1</td>
<td>47</td>
<td>0,0992</td>
</tr>
<tr>
<td></td>
<td>var. 2</td>
<td>190</td>
<td>0,3585</td>
</tr>
<tr>
<td>VA-BS</td>
<td>var. 1</td>
<td>40</td>
<td>0,1727</td>
</tr>
<tr>
<td></td>
<td>var. 2</td>
<td>40</td>
<td>0,0634</td>
</tr>
<tr>
<td>PO-BS</td>
<td>var. 1</td>
<td>56</td>
<td>0,3585</td>
</tr>
<tr>
<td></td>
<td>var. 2</td>
<td>86</td>
<td>0,0694</td>
</tr>
<tr>
<td>SF-VA</td>
<td>var. 1</td>
<td>44</td>
<td>0,1053</td>
</tr>
<tr>
<td></td>
<td>var. 2</td>
<td>40</td>
<td>0,0996</td>
</tr>
<tr>
<td>SL-PZ</td>
<td>var. 3</td>
<td>71</td>
<td>0,1009</td>
</tr>
</tbody>
</table>

Fig. 9. Comparison of variants of the number of sections the route Sofia - Plovdiv

Fig. 10. Comparison of variants of the number of sections the route Plovdiv - Burgas

To assess the variants was introduced an evaluation coefficient:

\[ K_{Var} = \frac{Var_{qL}^{\text{basic}}}{Var_{qL}^{\text{var}}}, \]

where: \( Var_{qL}^{\text{basic}} \) is the fuel consumption for the basic variant, \( Var_{qL}^{\text{var}} \) is the fuel consumption for the basic variant \( i \), l. The variant with a minimum number of sections are considered as a basic.

Coefficient \( K_{Var} \) shows the deviation of the results of variants with a larger number of plots compared to the basic.

Table 5 shows a comparison of fuel consumption for routes and is defined the value of the coefficient \( K_{Var} \).
Tab. 5. Comparison of variants

<table>
<thead>
<tr>
<th>Route</th>
<th>PO-DE</th>
<th>SF-VA</th>
<th>SF-DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>Var.1/Var.2</td>
<td>Var.1/Var.3</td>
<td>Var.1/Var.2</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Modeling the movement of road trains at a large number of sections and evaluation of energy efficiency is more precisely to carry out research with the differentiation of the routing of a larger number of sections. The error of modeling with a reduced number of sections is about 10%. For different routes the error has different values.

At a predetermined cost of fuel consumption with a minimum number of sections and known assessment factor may be adjusted value of fuel, i.e.:
\[
(11) \quad \frac{\text{Var}_1^L}{\text{Var}_{\text{basic}}^L} = \frac{\text{Var}_1^L}{\text{Var}_{\text{basic}}^L} \cdot K_{\text{corr}},
\]
\[
(12) \quad K_{\text{corr}} = 1 + (1 - \text{Var}_1^L),
\]
where: \( K_{\text{corr}} \) is the correction coefficient.

6. Approbation of the GPS

For the experimentation of system for evaluation of energy efficiency of movement of the train is made experiment. The mobile device for satellite navigation is fitted on vehicle and is made monitoring of movements in real time from workplace positioned at the Technical University - Sofia. The workstation is equipped with a computer to obtain the data. The type of device is shown in Fig. 15.

The mobile device is 5-channel and is made of firm Traffic control [4]. It consists of a receiver of signals from satellites and modules to store and transmit the coordinates of the object. Its action is to obtain coordinate data from the receiver of signals recorded in the module for storage and devoted information in Operational center by Transmission Module. The Operational Center is located in Stara Zagora. Received data are analyzed and transmitted to the workplace of the operators at the Technical University - Sofia in text or graphic form.

The system is experiment on the route Sofia - Plovdiv - Burgas and Sofia - Karlovo - Burgas. Fig. 16 shows a map of the routes. The system considers any changes in the altitude range of 1-5 m. For the two routes are recorded a total of 1850 observations in real time.

The system allows the following screen:
- Preview the route on the map, fig. 16.
- Chart of speed of movement, fig. 17.
- Chart of altitude, fig. 17.
- Visualization of the data obtained from the CPS - system-data on date of travel, hours, minute, and second; geographical coordinates (latitude and longitude); altitude in meters; speed of movement, km/h, fig. 18.

The information about the location and speed of the vehicle shall be made in real time and record of the working computer. The input information is displayed in a table in Excel (fig18). Additionally, is perform computational procedures to determine the distance between two consecutive points of the route (fig. 19).

The table is shown in fig. 19 and contains the following columns:
- Columns with primary data from the GPS system (yellow):
  - A – Data about of the trip date, hour, minute and second when changing altitude.
  - B – Data for geographical coordinates (latitude and longitude) recorded consistently measured in degrees.
  - C – Altitude (amplitude) in meters.
  - D – Movement speed, km/h.
• Columns for calculating the distance (purple):
  - U – Determination of the distance between two consecutive points of the route, according to geographic coordinates by formula (2);
  - V – Determination of the distance between two consecutive points of the route, according to speed and travel time by formula (3);
• Auxiliary columns. They serve to further transformations.
  - E and F. Their purpose is to determine time travel between two consecutive points of the route by formula (4).
  - G and M. Serve as an independent record of the latitude and longitude.
  - H, I, J, K, N, O, P are additional columns for ancillary transformations associated with geographical coordinates.
  - R and S. Serve to convert geographic coordinates in radians.
  - L and Q. They are used for converting geographic coordinates in decimal by formula (1).

The determination of the distance between two consecutive observations in both ways (formulas 2 and 3) give comparable results. The difference in calculated values is 0.92%.

7. Conclusions
New in the research is:
• It is developed a method and criteria for dividing the route into sections which can be applied to assess energy efficiency.
• Are introduced an evaluation and correction coefficient to determine the number of rational sections.
• It is experiment a satellite navigation system.
• It is studied the movement of vehicles in real time.
• It is experiment in real-time functional methodology for modelling the movement of road train and assesses the energy efficiency.

The study gives reason to make the following important conclusions:
- The separation of sections of the route depends on the character of the road profile and the parameter value on the road. In routes with smooth changes in road profile for the parameter for the formation of section can be assigned higher values.
- To make preliminary assessments the route can be divided into fewer sections for which to apply the model to evaluate the energy efficiency of movement. The results obtained may be determined by a correction factor. For taking managerial decisions and selection of optimal routes it is necessary to make division of a larger number of sections and precise fuel consumption.

For a transport company, with business is the transport of road trains, the functional system for energy efficiency may include the following possibilities: planning the movement of road trains on predefined criteria; determination of the shortest, fastest or most economical in fuel consumption route; the choice of the most appropriate routes to cycle through objects in a set list; drawing up the job to work on the basis of the calculated time and description of the route; map of the planned routes with actual.

To obtain additional information in real time for the means of transport, it can be equipped with sensors, related to GPS, such as a sensor for fuel consumption; sensor for load per axle of the vehicle, etc.

9. Acknowledgments
The investigations are supported according to contract № ДВВУ/2/51 20.12.2010, „Application of improved communication system for investigation and raising of efficiency of road trains in movement at motorway road conditions” funded by “National Science Fund – Ministry of Education, Youth and Science”.

8. References