Method of Astronomical Design of Arctic Roads

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Abstract. A method of designing roads, based on Arctic territories is described. Results of GPS-shooting are used for consideration of effect of sun blinding (SBE) of drivers and determination of dangerous because of sun sectors of road. Design of the road is held in special original software. When the road plan is designed, they consider SGE as a choice of such an azimuth of a road, within which the period of SBE would be minimal. Derivation of a road plan takes into consideration azimuth and meridian of specific road sectors in the Arctic. Geodesic position of main points of a road is specified on the basis of GPS-shooting. Azimuths of straight sectors of a road are calculated upon the points mentioned above. Apart from direction of the road azimuth, longitudinal slope, latitude and longitude of road track effect SGE. Introduction of given variables values is taken into account by the software to adjust the date and time of SGE on the surveyed section of the road. The values of all azimuthal coordinates are set in degrees and minutes in specially designated text fields under each graph. The aim of the method is to increase road safety, taking into consideration reduction of the negative impact of solar glare on the driver’s visual organs, which reduces visibility distance and attention-shifting; narrows eyeshot, etc. Under SBE conditions, the driver focuses on a small field of vision located in the course of movement and ignores outlying information. The method takes into account all the factors affecting driving of a vehicle in the conditions of SBE. Application of the method of astronomical design allows to develop operational measures to reduce the accident rate in sun-hazardous areas.

1. Introduction
Effects of traffic accidents caused by the sun blinding are characterized by extreme gravity due to the fact that they happen in high traffic activity coinciding with peak hours in communities and with the reduction of visual information about traffic due to blinding of a driver.

Traffic accidents’ analysis in the cities of the Far Eastern Federal District (FEFD) shows that every year 4.7 per cent traffic accidents (TA) take place, where the main or concomitant factor was sun blinding [10]. Moreover, there’s a tendency of the yearly growth of the mentioned accidents due to increasing of traffic intensity and speed.

Accidents on sun-dangerous road sections are classified as very severe. Average participants in one accident are 3.9 per cent, with 59.4 per cent of them being injured and 2.8 per cent killed [10].

In days, when the effect of sun blinding (SBE) is intensive, technical speed on the route is heavily reduced and transport enterprises suffer losses. Due to this fact in some regions of Russia the idle time index per year total 268 hours or about 33 work orders. According to the preliminary calculations our National economy loses about 25 billion rubles per year due to the negative impact of SBE [11].
Drivers’ blinding during daytime, as a natural phenomenon negatively affecting the consumer properties of roads and traffic safety, has not been studied yet. Bright sunlight is one of the most negative natural factors for driving, which deforms or impairs the perception of traffic circumstances.

2. Methodology

Sun blinding first of all affects a driver’s visual organs: visual distance gets shorter, attention switchability lessens, line of sight narrows, etc [13].

In SBE conditions a driver concentrates his attention on a short sight line, situated ahead and ignores peripheral information. This leads to the shortening of a period for processing of incoming information by his random access memory, resulting a driver not always estimates the meaning of incoming information correctly, he throws away information, important for traffic safety, together with waste facts. This, in turn, leads to increasing of traffic accidents.

The researches show that psycho-physiological conditions of a driver depend on the sun light intensity. It should be considered that with the pulse frequency more than 120 beats per minute there comes an overload of a driver’s psycho-physiological condition [10].

The analysis of results obtained allows us to conclude that within the sun blinding a driver’s pulse frequency is increased by 18–33 beats per minute. The average value of pulse frequency growth is 25,5 beats per minute.

The results of my researches show that the sun-blinding effect contributes to more rapid fatigue and decrease in efficiency of a driver [9, 14]. Frontal sun blinding leads to a distortion of traffic circumstances, and sometimes a sun-blinded driver cannot adequately perceive traffic circumstances at all. Sun blinding forces a driver to change a trajectory and to slow down up to full stop. Due to sun blinding a driver cannot adequately consider all traffic factors. This often leads to emergency situations and traffic accidents. A driver’s sun blinding occurs not only when the sun is ahead but often when it is behind. The blinding in the second case occurs with the help of a rearview mirror.

The agenda at hand is especially topical when SBE coincides with peak hours in traffic intensity. Many years of SBE researches allows me to give this phenomenon the following definition:

The driver’s sun-blinding effect is a psycho-physiological process taking place during some period of time necessary for a transition to a new level of sight adaptation due to a fast change in brightness of traffic circumstances observed by a driver. It results from the loss of visual perception and deterioration in emotional condition of a driver.

When designing a road it is necessary to provide for decisions leading to decreasing negative impact of natural and climatic factors [1, 8, 19, 20], including a driver’s sun blinding [4, 10]. The choice and argument of decisions to provide for a road’s consumer properties should be made according to driver’s features of perception for traffic situation [3, 6, 15, 17].

When designing of variants of a road plan, registration of the sun-blinding effect means the choice of such an azimuth of the road that lets the period of sun blinding be minimal. There are different decisions for this in different countries. At the same time, the designer tusk is to decrease the quantity of drivers’ azimuth combinations with azimuth of sunrise and sundown.

The decision of this tusk consists of the three stages:
1 – determination of variant azimuth of traffic participants;
2 – determination of azimuth of sunrise and sundown for a given location;
3 – choice of optimal azimuth for traffic participants/

Based on GPS data on the first stage the geodetic coordinates of specific road points are being determined, which help to calculate azimuth of straight road sections. In the example, given below (Figure 1), point 0 is a start of the rout (RS), point 1 is a corner vertex (CV), point 2 is an end of the rout (RE).
To define the geographical coordinates of longitude ($\lambda$) and latitude ($\varphi$) the navigators can be used (Garmin, for example) as well as the satellite receivers of geodetic type.

The most perspective thing for this definition is the satellite GPS filming of a road’s axis, as a result of its processing they get dimensional coordinates of the filmed points.

The satellite receivers of geodetic type are used for the precise definition of coordinates of a place where the receiver is placed in coordinate system the user has chosen. Receivers help to measure distances to the defying points in a static mode of measuring with inaccuracy of 5 mm+lppm at range of measurements up to 20 and 50 km respectively.

Primary measurements of point positions in a world geodetic coordinates system WGS-84 are made with the help of GPS receivers. On the second stage a transfer to local coordinates systems of the user (for example, to the zonal flat rectangular coordinates system of 1942 SK-42 and the Baltic heights system) is made with the help of software tools. Eventually, flat rectangular coordinates X, Y are defined as well as heights H of search points in the used cartographic projection of a reference ellipsoid on a plain and in the system of absolute (normal) heights.

A classic set of geodetic GPS equipment consists of two receivers for collecting of draft satellite data, a storage controller and other accessories. A controller is a mini-computer for managing projects and receivers’ settings. It is also used for receiving field data.

The processing of draft GPS data imported from receivers or a storage controller to the computer is done in post-processed mode with the help of special software package.

Special mathematical calculations help to define azimuth of the given road section, the results being placed to table. In this table each straight section is indicated in two oppositely directed azimuths.

On the second stage azimuths of sunrise and sundown for the given location during a year are defined. The position of the Sun in any point of the Earth is defined by the elevation angle $h$ and azimuth $A$. They are defined using the formula by B. J. Brinkworth [7].

$$\sin h = \cos \varphi \cos \delta + \sin \varphi \sin \delta \quad (1)$$

$$\sin A = \frac{\cos \delta \sin \tau}{\cos h} \quad (2)$$

were $\tau$ is the angle, characterizing the Sun’s angular movement about the midday axis in accordance with the time $t$ after noon, the Sun’s declination $\delta$, the latitude of a location $\varphi$.

The full Sun circle of 360º takes place in 24 hours, thus the bias $\tau$ is defined by the formula 3.

$$\tau = \frac{t}{24} \quad 360º = 15 \ t \ (\text{degrees})$$

$$\quad (3)$$
During sunrise and sundown $h = 0$, thus the formula 2 looks like more simple formula 4 and the formula 1 converts into the formula 5.

\[
\sin \Lambda = \cos \delta \sin \tau \tag{4}
\]

\[
\cos \tau = -\tan \varphi \tan \delta \tag{5}
\]

Let’s place values from the formula 5 into the defining azimuth formula (4), after which in the defining azimuth formula the angle of declination and geographical latitude will still be variable.

\[
\sin \Lambda = \cos \delta \sin (\arccos (-\tan \varphi \tan \delta)) \tag{6}
\]

The angle of declination of the Sun during a year is measured for each day by the Sun’s ephemeris [6] or is counted according to the following formula.

\[
\delta = \frac{23.5 \times 2 \times \pi}{360} \sin \left( \frac{2 \pi d}{365} \right) \tag{7}
\]

where $\pi$ is 3.12, $d$ is a number of days passed since the day of spring equinox (the 21st of March).

During a year the angle of declination is changing from $+23^\circ 27'$ in summer solstice to $-23^\circ 27'$ in winter solstice, going through 0 twice a year, thus we place the bordering values of the angle of declination in the formula 6. One of the bordering values of the azimuth will be reached when $d = 365$. Another one complies to the number of days $-91$ or $274$, which complies with the maximum value of the angle of declination on the day of solstice.

The analysis of a road’s azimuths as well as sunrise and sundown will show if the road’s section being designed would be subject to SBE during a year. If there are such sections they need to make a variant design with the values of the rout’s azimuths never coinciding with the azimuth of sunrise and sundown.

With the aim of defining the sun dangerous sections under my direction the special program was developed, which allows to reveal dangerous sections while road designing. This program’s algorithm includes three stages: I – definition of azimuth of a road being surveyed, II – definition of azimuth of sunrise and sundown for a given location, III – definition of a day and time of SBE.

The road’s azimuth processing is isolated into a separate subsystem with a row of governing bodies and with the opportunity to automatically recalculate data between them (Figure 2). Azimuth input is made for the direct (two upper schedules) or reverse (two lower schedules) direction of a given road section. The direction is shown in degrees and minutes of azimuth coordinates in reference to the north or in rhumbs. Data calculation of ESB, as well as sunrise and sundown time for ESB dates is made automatically.

Besides the directions of roads’ azimuth the period of SBE is affected by the longitudinal bias, latitude and longitude of the rout’s location. The values of data variables input is being considered by the program in case of correcting the date and time of ESB on a surveyed road section. All azimuth coordinates values are set in degrees and minutes within special text boxes under each schedule.

The analysis of a road’s azimuth as well as sunrise and sundown shows in which time and day these particular road sections would be subject to the sun-blinding effect during a year. Earlier considered method of road design with ESB in mind, proposed by P. A. Pegin, gives a strong chance to preliminary assess ESB. With the certain Sun trajectories a scheme-schedule of daily ESB duration’s apportion on the given road sections is built [11, 12].

Originally we need to build a circular schedule of daily sunrise and sundown, connected with coincident days of the year. This obtained schedule is placed on the map to define the sun-dangerous sections (Figure 3). Based on the results obtained, the Sun’s position during a year and potentially dangerous sections with the sun-blinding effect are defined.
Figure 2. The situation of bodies governing “ESB-09” program

1 - sunrise and sunset time calculation, 2 - accounting for daylight saving time, 3 - Brisbane, Khabarovsk, 4 - longitude, 5 - height above sea level, 6 - direct glare effect, 7 - longitudinal slope, 8 - ppm, 9 - sun glare effect in the opposite direction, 10 – degree, 11 – minutes, 12 - rumba reverse, 13 - azimuth reverse, 14 - straight rumba, 15 - azimuth straight, 16 – latitude, 17 - time zone, 18 - year
3. Conclusion

The importance and relevance to solve problems of SBE influence on providing for traffic safety are admitted by all the organizations involved in the road industry. This problem has become especially urgent nowadays in connection with a great increase in the number of cars [2].

It’s hard to highlight the influence of certain factors on traffic safety, because, besides their direct effect, they are combined with each other [16]. So, in designing a road it’s necessary to take into consideration all the external factors and their interaction.

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