Analysis of the Influence of Sun Glare on Traffic Accidents in Japan

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Abstract: Sun glare is known to adversely affect driving conditions, and some measures against traffic accidents from sun glare have been implemented. Quantitative analysis of the influence of sun glare on traffic accident occurrence has not been carried out, so the seriousness of such glare as a traffic safety problem is unknown. The Chiba Prefectural Police Headquarters has been recording latitude and longitude of the accident location and vehicle travel direction as additional data items for traffic accidents in the prefecture. We used these additional data items to analyze the degree to which sun glare affects traffic accident occurrence. It was found that when the sun is in a position that tends to blind drivers, traffic accidents tend to be more frequent. The effect of sun glare on accident occurrence was quantified and was found to be very adverse.

Key Words: solar position, traffic accident, glare, sun

1. INTRODUCTION

It is widely known that the likelihood of traffic accidents depends on weather conditions. Many studies have shown that adverse weather, such as rain or snow, increases the likelihood of traffic accidents. It is believed that sun glare also adversely affects traffic conditions, so traffic safety measures against sun glare have been implemented.

One example is the sun visor that is equipped on upper inside of the front windshield. However, these cover only a small portion of the front windshield, and it is impossible for such visors to completely screen out the sun. At dusk and dawn, when the sun located near the horizon, it is impossible for a visor to protect against sun glare.

With respect to traffic safety facilities, it is a serious problem for drivers to have difficulty recognizing traffic lights because of sun glare, so light-emitting-diode (LED) traffic signals have been introduced at many intersections, and the visual conditions experienced by the driver at signalized intersections have been enhanced.

The serious problem of sunlight blinding drivers has not been solved, so it is assumed that sun glare hinders road traffic safety. However, quantitative analysis on the effect of sun glare on traffic accident occurrence has not been carried out, so the seriousness of sun glare as a traffic safety problem has remained unknown.

2. REVIEW
Kojima and Takubo (1987, 1988, 1989) analyzed how various adverse weather conditions affect driving safety. Regarding side winds, they analyzed traffic accident occurrence on a section of the Tohoku Expressway that sometimes has strong sideways gusts (1987). Regarding rainfall and wet road surface, they showed that the likelihood of traffic accidents is higher under rainy conditions than under rain-free conditions (1988), and that visibility reduction is also a serious problem (1988). Regarding snowfall, snow accumulation and road surface freezing, they showed that no injury accident, that is, slight accident had occurred more than under snow-free condition on national highway in Akita Prefecture, Japan (1989). Nishida (2009) analyzed traffic accidents on expressways under rainy conditions and showed that the likelihood of traffic accidents on expressways is higher under rainy conditions than under rain-free conditions in many prefectures of Japan.

In addition to this research, many other studies focusing on how adverse weather conditions affect road traffic conditions have been carried out in Japan. Most of this research showed that adverse weather adversely affects road traffic conditions. However, the effect of sun glare, an adverse road traffic condition, on road traffic conditions had not been quantified in Japan. This study aimed to determine the solar position and vehicle travel direction at the time of each traffic accident, and to analyze the influence of sun glare on traffic accident occurrence, based on traffic accident data from Chiba Prefecture, Japan.

3. TRAFFIC ACCIDENT DATA

In Japan, standard items of traffic accident data are specified by the National Police Agency (NPA). All traffic accidents resulting in injury are included in this database. Local police departments are required to keep records of traffic accidents and to share these records with the NPA. NPA regulations state that the following be recorded: occurrence time and address, road traffic environment (weather, road condition, etc.), accident type, driver attributes (driver age and gender) and vehicle attributes (vehicle type), safety facilities, etc. However, these items do not permit the solar position and vehicle travel direction to be determined.

The Chiba Prefectural Police Headquarters specifies the additional items of accident latitude and longitude, vehicle travel direction. From these it is possible to calculate the solar position. Using the traffic accident data from Chiba Prefecture, we determined how much the sun glare affects traffic accident occurrence.

4. CALCULATING THE SOLAR POSITION AT THE ACCIDENT TIME AND LOCATION

As shown in Figure 1, the solar position at the accident time and location was represented by utilizing the solar zenith angle ($\theta$) and azimuthal angle ($\chi$). The solar zenith angle is the angle between the vertical line extending from the accident location to the Zenith and the line extending from the accident location to the sun. The greater is the solar zenith angle, the lower is the sun. When the solar zenith angle exceeds 90 degrees, it is night.
The solar azimuthal angle means the angle between a line pointing to the North Pole and a line to pointing to the solar position on the horizontal plane at the accident location. So the solar azimuthal angle of the line to the North Pole is 0 degrees, and the angle is defined from 0 to 360 degrees clockwise. The vector of vehicle travel direction is also defined as angle from 0 to 360 degrees clockwise.

Formulae for calculating the solar zenith angle and azimuthal angle are explained here. The cosine of the solar zenith angle ($\cos \theta$) was calculated using solar declination ($\delta$), latitude of the accident location ($\varphi$) and hour angle ($t$) (Formula (1)), and the solar zenith angle was calculated as

$$\cos \theta = \sin \delta \sin \varphi + \cos \delta \cos \varphi \cos t$$  \hspace{1cm} (1)

where

- $\theta$: solar zenith angle (rad)
- $\delta$: solar declination (rad)
- $\varphi$: latitude (deg., at accident location)
- $\lambda$: longitude (deg., at accident location)
- $t$: hour angle (deg.)

Solar declination depends on day of the year (Julian day), so it is calculated using Formula (2)

$$\delta = 0.006918 - 0.399912 \cdot \cos A + 0.070257 \cdot \sin A$$

$$- 0.006758 \cdot \cos (2A) + 0.000907 \cdot \sin (2A)$$

$$- 0.002697 \cdot \cos (3A) + 0.00148 \cdot \sin (3A)$$  \hspace{1cm} (2)

$$A = \frac{2\pi J}{365}$$  \hspace{1cm} (3)
where

\( J \): day of the year (Julian day)

Hour angle is calculated using Formula (4).

\[
t = 15 \frac{\pi}{180} (TST - 12)
\]  

(4)

\[
TST = MST + ET
\]

(5)

\[
MST = GMT + \frac{\lambda}{15}
\]

(6)

\[
ET = (0.000075 + 0.001868 \cos A - 0.032077 \sin A - 0.014615 \cos (2A) - 0.040849 \sin (2A) \lambda 2/\pi)
\]

(7)

where,

TST: true solar time
MST: mean solar time (or local time)
GMT: Greenwich mean time
ET: equation of time

As a first step to calculate the solar azimuthal angle, the sine and cosine of \( \varphi \) was calculated using solar declination \( (\delta) \), hour angle \( (t) \) and solar zenith angle from Formulae (8) and (9)). The values of sine and cosine of \( \varphi \) were then

The calculated values of \( \sin \varphi \) and \( \cos \varphi \) are classified into cases, and \( \chi_1 \) and \( \chi_2 \) were calculated as follows.

\[
\sin \varphi = \cos \delta \cdot \frac{\sin t}{\cos \varphi}
\]

(8)

\[
\cos \varphi = -\cos \varphi \sin \varphi + \sin \varphi \cos \varphi \cdot \cos \cdot \cos \varphi
\]

(9)

where

- \( \cos \varphi < 0, \varphi_1 = 2\varphi - \varphi \)
- \( \cos \varphi > 0 \& \sin \varphi < 0, \varphi_1 = 3\varphi + \varphi \)
If \( \cos \theta \) and \( \sin \theta \) do not fit the two above-mentioned conditions then 
\[
\theta_1 = \theta + \theta
\]
where
\[
\theta_1 > 2 \pi \quad \theta_2 = \theta_1 - 2 \pi
\]
If the calculated \( \theta_1 \) is less than \( 2\pi \), then this is the solar azimuthal angle; otherwise the solar azimuthal angle is \( \theta_2 \), which is \( \theta_1 \) minus \( 2\pi \). Therefore, the calculated \( \theta_1 \) or \( \theta_2 \) that is less than \( 2\pi \) is the solar azimuthal angle.

5. METHOD

31,161 traffic accidents occurred in Chiba Prefecture in 2007. 18,042 accidents that meet the following two requirements were selected for analysis:

Requirement 1
The “first party” (i.e., the party most responsible for causing the accident) is the driver of a vehicle that is larger than a moped. However, accidents in which the first party is missing are excluded, such as hit-and-run accidents.

Requirement 2
The weather is classified as “fine,” according to the five-category weather index of fine, rainy, cloudy, snowy and foggy. Of the 18,042 accidents that were selected, 13,316 daytime accidents were analyzed for the influence of sun glare and 4,726 after-sunset accidents were analyzed as the control.

Utilizing these selected accident data, the solar zenith angle and the azimuthal angle at the accident time and location were calculated in order to include them in Formulae (1)–(9). Using the accident data, such as accident type and occurrence time, together with the calculated solar zenith angles and the azimuthal angles, we analyzed the influence of sun glare on the accidents.

6. RESULTS

6.1 Analysis by Occurrence Time

As mentioned above, it is possible to calculate the solar position at the accident occurrence time, so the solar zenith angle was calculated using Formula (1). A solar zenith angle of less than 90 degrees means a daytime accident; one of greater than 90 degrees means a nighttime accident.

The position of the sun relative to the vehicle travel direction is described as the difference between the azimuthal angle of the sun and the travel direction of the first party (Figure 1), or “the difference in azimuthal angle”. If the difference in azimuthal angle is between -180 degrees and 180 degrees, then the difference is used as it is. If the difference in azimuthal angle is less than -180 degrees, then 360 degrees is added to that difference. And if the difference in azimuthal angle exceeds 180 degrees, then the 360 degrees is subtracted from that difference. So if the sun is to the right of the line of travel direction, then the difference in
azimuthal angle is greater than 0 degrees; otherwise, the difference is less than 0 degrees. The calculated difference in azimuthal angle is rounded off to nearest 20 degrees. 0 degrees means that the difference is from -10 degrees to 10 degrees. As shown Figure 2, more traffic accidents tend to occur when the sun is in front of the vehicle than when the sun is at other positions. As a control, Figure 2 shows evening accident data in which the accident numbers are largely stable regardless of the calculated differences in azimuthal angle between the sun and vehicle.

The orientations of roads are independent of solar position and most roads have ups and downs, so the vehicle travel direction and the solar azimuthal angle are independent of each other. Because azimuthal angle between the sun and the vehicle indicates the location of the sun with respect to the driving direction, the frequency of the occurrence of an azimuthal angle between the sun and the vehicle for the driver should be the same for any azimuthal angle. Then, the frequency of occurrence of the azimuthal angles for a 20-degree range should be the same as that for any other 20-degree ranges. Now, we can obtain the number of accidents for each 20 degrees from our 13,316 daytime accident data. The number of accidents when the sun is in front of the driver (i.e., when the difference in azimuthal angle < +/-10 degrees) is higher than the numbers of accidents for any other 20-degree range. Consequently, we can say that traffic accidents tend to increase during daytime when sun glare affects drivers.

![Figure 2](image)

Figure 2 Numbers of traffic accident according to the difference in azimuthal angle between the sun and vehicle

### 6.2 Analysis by Solar Zenith Angle

At the latitude of 35 degrees 30 minutes north (the Chiba Prefectural Office is at 35 degrees 36 minutes north), the meridian latitude at the summer solstice is about 78 degrees and the meridian latitude at the winter solstice is about 31 degrees. So the solar zenith angles at the summer and winter solstice are about 12 and 59 degrees, respectively; therefore, the sun at the meridian always has a zenith angle of no less than 59 degrees and no more than 12 degrees.

Table 1 shows the numbers of traffic accidents according to the solar zenith angle. The “East (Morning)” column in Table 1 lists traffic accidents that occurred when the sun was in the east, and the “West (Evening)” column lists traffic accidents that occurred when the sun was in the
Traffic accidents for solar zenith angles of more than 90 degrees are not shown; only daytime traffic accidents were analyzed. It is obvious that more traffic accidents occurred when the solar zenith angle was between 50 and 80 degrees. When the angle was more than 80 degrees, i.e., the sun was near the horizon, traffic accidents decreased.

The increase in accidents for solar zenith angles of 50 to 80 degrees is attributed to the driver being blinded by sun glare. When the angle is more than 80 degrees, the sun tends to be hidden by buildings or topographic features. When the solar zenith angle was more than 70 degrees, traffic accidents with an eastern solar position tended to occur less than those with a western solar position. This is attributed to the low traffic volume at dawn.

### Table 1 Numbers of traffic accident according to solar zenith angle

<table>
<thead>
<tr>
<th>Solar Zenith Angle</th>
<th>Traffic Accident Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-80 degrees</td>
<td>Increase</td>
</tr>
<tr>
<td>80-90 degrees</td>
<td>Decrease</td>
</tr>
<tr>
<td>&gt;90 degrees</td>
<td>Not shown</td>
</tr>
</tbody>
</table>

#### 6.3 Analysis by Accident Type

Traffic accidents in daytime were analyzed by type. Figure 3 shows the Share of traffic accidents of each type according to the difference in azimuthal angle between the sun and vehicle. According to this figure, vehicle-to-pedestrian accidents and vehicle-to-vehicle, vehicle-alone and train-crossing accidents tend to occur more when the difference in
azimuthal angle is near 0 degrees. Vehicle-to-person accidents tend to occur much more when
the difference in azimuthal angle is near 0 degrees. This is attributed to the vehicle driver
tending to find it difficult to recognize pedestrians because of the sun glare.

6.4 Analysis by Vehicle-to-Vehicle Accident Types

Of the 11,992 vehicle-to-vehicle, vehicle-alone and train-crossing accidents (Figure 3),
vehicle-to-vehicle accidents excluding vehicle-alone and train-crossing accidents account for
11,802. For vehicle-to-vehicle accidents, the share of traffic accidents according for each
range of azimuthal angle was analyzed.

Vehicle-to-vehicle accidents consist of ones of “rear-end,” “frontal collision”, “left/right
turning,” etc. Figure 4 shows the share of each type of vehicle-to-vehicle accident according
to the difference in azimuthal angle between the sun and vehicle. Although the magnitude is
not as large as the analysis of vehicle-to-pedestrian accidents (Figure 3), vehicle-to-vehicle
accident occurrence ratios of head-on-collision and right/left turning at around the 0 degrees
of the difference in azimuthal angle is higher than the difference in azimuthal angle of for
from 0 degrees. Frontal collisions and left/right turning accidents tend to occur slightly more
when the difference in azimuthal angle is near 0 degrees. It is supposed that these types of
accidents are more influenced by sun glare than the other types of vehicle-to-vehicle
accidents are.

6.5 Number of Traffic Accidents Influenced by Sun Glare in Japan

Solar azimuthal angle and vehicle travel direction are independent events. So if sun glare does
not affect traffic accident occurrence, the number of traffic accidents in each 20 degrees of
difference in azimuthal angle would be roughly the same. Figure 2 shows that the number of
daytime accidents remains roughly constant once the azimuthal angle reaches +/-70 degrees.
So, up to the azimuthal angle of +/-70 degrees, increases in traffic accidents can be attributed
to sun glare. The number of traffic accidents in Figure 2 was simplified as the bold line in
Figure 5, and it was assumed that the gray area is the number of traffic accidents caused by
sun glare. The amount of increase by sun glare was estimated.
Traffic accidents in Chiba Prefecture numbered 31,161 in 2007. Of these, 13,316 traffic accidents occurred in daytime under fine weather. Traffic accidents in which the difference in azimuthal angle exceeds +/-70 degrees number 7,817. Each 20-degree of difference in azimuthal angle results in an average change of 710.6 accidents. Therefore, within a 20-degree range of azimuthal angles for azimuthal angles exceeding +/-70 degrees, an average of 710.6 accidents was regarded as the standard number of traffic accidents in daytime, and this was compared with the number of traffic accidents within a 20-degree range of azimuthal angles for azimuthal angles not exceeding +/-70 degrees. Using this, the total number of accidents caused by sun glare was calculated (Formula 10), and that number was 524.5 traffic accidents in 2007 in Chiba Prefecture.

\[
\sum T_{IbySC} = \sum (NoA - 710.6) \tag{10}
\]

where
- \(T_{IbySC}\): total influence of sun glare on traffic accidents in Chiba Prefecture
- \(NoA\): the number of accidents of each 20 degree range for the difference in azimuthal angle within +/-70 degrees

Traffic accidents in Japan numbered 832,454 in 2007. Using our calculations of the influence of sun glare on accidents in Chiba Prefecture, we extrapolated that influence for all of Japan (Equation 11). It was estimated that 14,013 traffic accidents in Japan could be attributed to sun glare, making this a very serious problem.

\[
\sum T_{IbySJ} = \sum T_{IbySC} \frac{T_{AinJ}}{T_{AinC}} \tag{11}
\]

where
- \(T_{IbySJ}\): total influence by sun glare in Japan
- \(T_{AinJ}\): total of accidents in Japan
- \(T_{AinC}\): total influence on traffic accidents in Chiba Prefecture
7. CONCLUSION

Using traffic accident data from Chiba Prefecture that include the additional items of accident latitude and longitude and vehicle travel direction, the solar position at each accident time and location was calculated. The effect of sun glare on traffic accident occurrence was determined.

It was found that accidents tend to be more frequent when the sun is in a position that blinds the first party in an accident. So it was proved that sun glare is a factor in traffic accidents.

Analysis of sun glare according to traffic accident type (vehicle-to-pedestrian, left/right turning, and frontal) found that accidents tend to occur more when the sun is at/near the front of the first party involved. Therefore it is supposed that the closer to the front the sun is, the more difficult it is for vehicle drivers to detect pedestrians. In contrast, when drivers face complicated tasks, such as turning or passing through an intersection, traffic accidents tend to occur more when the sun is located in/near front of the vehicle of the first party. In a driving situation with complicated tasks, it is supposed that sun glare is particularly likely to contribute to accident occurrence.

8. FUTURE DIRECTIONS

One task for the future is to calculate accident frequency according to zenith angle. The position of the sun and the number of sunlight hours differ from location to location. We need to develop criteria that can be used to determine the daylight hours, to calculate the solar position, and to quantify the frequency of solar zenith angle for accidents.

And it is necessary to calculate the actual sunrise and sunset time at each accident location. When the solar zenith angle was more than 80 degrees, the number of traffic accidents decreased. It will be possible to quantify the influence of sun glare precisely on traffic accidents to calculate the actual sunrise and sunset time. To quantify the influence, it is necessary to calculate the sunshine duration at the accident location using Geographic Information System (GIS), which includes information on buildings and topographic features.

When the Sun is in front of the driver, the sun tends to have a particularly adverse affect on driving. When the sun is nearly in front of the driver, the sun has a particularly adverse affect on driving. Toward developing sun glare countermeasures, it will be necessary to quantify the range of influence. As shown in Figure 2, it is supposed that sun glare influences driving when the sun is in within 70 degrees right or left of center. It is necessary to examine the drivers’ angular visibility range from the standpoint of ergonomics.

The traffic accident data in this study were ones those for Chiba Prefecture. If vehicle travel direction is recorded in a nationwide traffic accident database, the influence of sun glare will be able to be analyzed in detail.

REFERENCES

Research on the Effect of Natural Disasters on Traffic Accident Occurrence (in Japanese)