The Effect of Sun Glare on Traffic Accidents in Chiba Prefecture, Japan

Kenji HAGITA [a], Kenji MORI [b]

[a,b] *Traffic Science Division, National Research Institute of Police Science, Chiba, 277-0882, Japan*
[a] *E-mail: hagita@nrips.go.jp*
[b] *E-mail:* mori@nrips.go.jp

Abstract: This study aims to clarify effect of sun glare on traffic accident occurrence. Traffic accidents analyses were carried out to calculate the position of the sun relative to the first vehicle concerned (i.e., the vehicle most responsible for causing the accident) at the accident time and spot by using the traffic accident database of Chiba Prefecture, Japan. The traffic accident rate was found to increase when the viewing angle decreased to less than 90 degrees. When the sun was in front of the first vehicle concerned, the accidents had occurred more for pedestrian accidents, bicycle accidents and accidents at intersection and slightly more for right-turning accidents and accidents in winter. However, the tendency for vehicle drivers to be affected adversely by sun glare was not observed to increase with increases in vehicle speed. Traffic safety measures against such kinds of accidents are needed.

Keywords: Traffic Accident, Sun Glare, Solar Position, GIS

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 installed on upper inside of the front windshield. However, this covers 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 near the horizon, it is impossible for a visor to protect against sun glare. Another example is the sunshade on full-face motorcycle helmets. Wearing sunglasses is a popular accident countermeasure, but it is effective only when the sun is in front of the driver; at other times, it can be counterproductive.

Regarding traffic safety facilities, sun glare poses the serious problem of making it difficult for drivers to recognize traffic signals, so light-emitting-diode (LED) traffic signals have been introduced at many intersections, and the visual conditions at signalized intersections have been enhanced. However, it is true that sun glare hinders road traffic safety, so the serious problem of sunlight blinding drivers has not been solved. Quantitative analysis on the contribution of sun glare to traffic accident occurrence is very important toward developing measures against the serious traffic safety problem of sun glare.

In light of the above, (Hagita and Mori ;(2011)[2), 3),4),5)]) analyzed sun glare as a factor contributing to traffic accidents. The traffic accident rate was found to be higher when the sun was in front of vehicle drivers. This suggests that many accidents occur because of sun glare. Pedestrian accidents and accidents at signalized intersection tend to occur at particularly high rates because of sun glare. However, heavy vehicle accidents did not show this tendency.

Using methods similar to those of earlier studies, the solar position at the accident time and spot, and the position of the sun relative to the first vehicle concerned (i.e., the vehicle most responsible for causing the accident) were calculated. The purpose of this research is to determine how sun glare factors relate to traffic accident occurrence. Logistic regression was used to analyze what aspects of sun glare affect traffic accident occurrence.

2. REVIEW

In studying how sun glare contributes to traffic accident occurrence in Japan, (Hagita and Mori ;(2011)[2), 3)]) found that the traffic accident rate tended to be higher when the sun was in front of the vehicle. Regarding pedestrian accidents (Hagita and Mori ;(2011)[4)]), they were found to occur with greater frequency than other types of accidents when the sun was in front of the vehicle. That paper did not find accident black spots at which sun glare was found to contribute to a higher rate of pedestrian accidents. Regarding accidents broken down by vehicle type (Hagita and Mori ;(2011)[5)]), it was inferred that sun glare in front of heavy vehicles did not increase the accident rate of such vehicles. Sun glare was found to contribute to accidents by two-wheeled vehicles when the sun was immediately in front of the vehicles. This is attributed to the fact that the viewing angle of two-wheeled-vehicle drivers wearing full-face helmet is narrower than that of other vehicle drivers.

Mitra (2008) showed that the traffic accident rates at dusk and dawn are higher than the rates at other times, in an analysis of traffic accident data, sunset and sunrise times, and road travel directions in Arizona, USA. This analysis was not precise, for three reasons. First, the road travel directions of the subjects were classified into only four categories: north, south, east and west. Second, the time periods in which sun glare was considered to contribute to traffic accidents were defined roughly as one hour after sunrise and before sunset. Third, the influence of weather was not addressed. (Jurado-Pina and Pardillo-Mayora ; 2009) estimated the solar position at the time of traffic accidents, and they suggested a way of analyzing sun-glare-influenced traffic accidents. Jurado-Pina *et al.*(2010) analyzed the adverse influence of sun glare at tunnel exits and suggested road designs to reduce sun glare. According to an analysis of traffic volume and travel speed during adverse weather, Daniel *et al.* (2009) showed that vehicle speed at dusk and dawn are lower than at other times.

So we see that many studies have addressed the effects of adverse weather, such as rain and sun glare, on road traffic. However, no studies other than Japanese ones have addressed how the weather and the position of the sun relative to the direction of the first vehicle concerned affect the rate of traffic accidents. Japanese traffic accidents data were analyzed to determine how sun glare factors relate to traffic accident occurrence.

3. METHODS

3.1 Traffic Accident Database in Chiba Prefecture

To calculate the position of the sun relative to the first vehicle concerned at the time of accident, it is necessary to acquire two items that are not included in the national traffic accident database in Japan: the latitude and longitude of the accident spot, and the vehicle travel direction. Because these two items are not collected in the national traffic accident database in Japan, we analyzed the traffic accident database for Chiba Prefecture, which does include these two items.

In Japan, traffic accident data to be collected 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 (age and gender), vehicle attributes (vehicle type), safety facilities, etc. However, these items do not permit the solar position and the vehicle travel direction to be determined.

The Chiba Prefectural Police Headquarters specifies the additional items of accident latitude and longitude, and vehicle travel direction. These data can be represented on a GIS, as shown in Figure 1. Vehicle travel directions of the first vehicle concerned are shown by black arrows, and those of the second vehicle concerned are shown by white arrows. Travel directions of single vehicle accidents are shown by only black one and travel directions of multiple vehicle accidents are shown by only black and white ones. The intersection of the two travel directions is the accident spot. From these traffic accident data, it is possible to calculate the position of the sun relative to the vehicle travel direction at the accident time and spot.

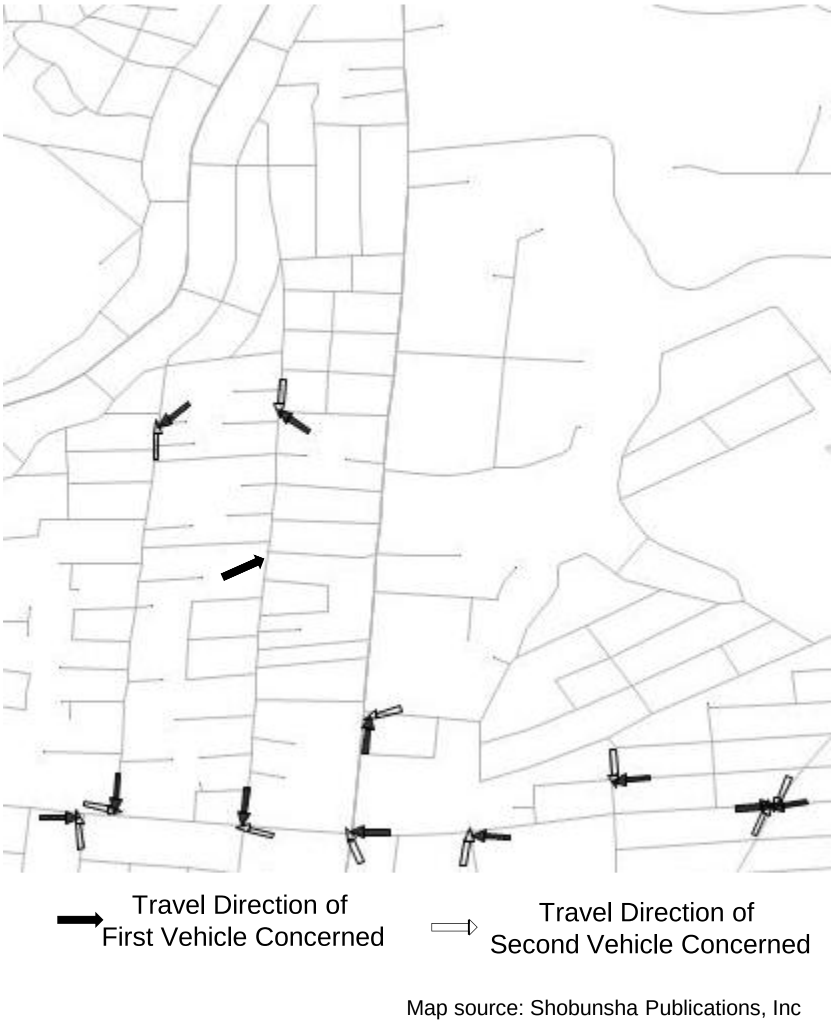

Figure 1. GIS representation of traffic accidents in Chiba, including vehicle travel direction

3.2 Calculating the solar position at the accident time and spot

As shown in Figure 2, the solar position at the accident time and spot is represented by solar zenith angle (θ) and azimuthal angle (χ). The solar zenith angle is the angle between a vertical line extending from the accident spot to the zenith and the line extending from the accident spot to the sun. The lower is the sun, the greater is the solar zenith angle. At solar zenith angles exceeding 90 degrees, it is night.

The solar azimuthal angle means the angle between a line pointing to the North Pole and a line pointing to the solar position on the horizontal plane at the accident spot. So the solar azimuthal angle of the line to the North Pole is 0 degrees, with the angle increasing from 0 to 360 degrees clockwise. Vehicle travel direction is also defined as an angle from 0 to 360 degrees clockwise.

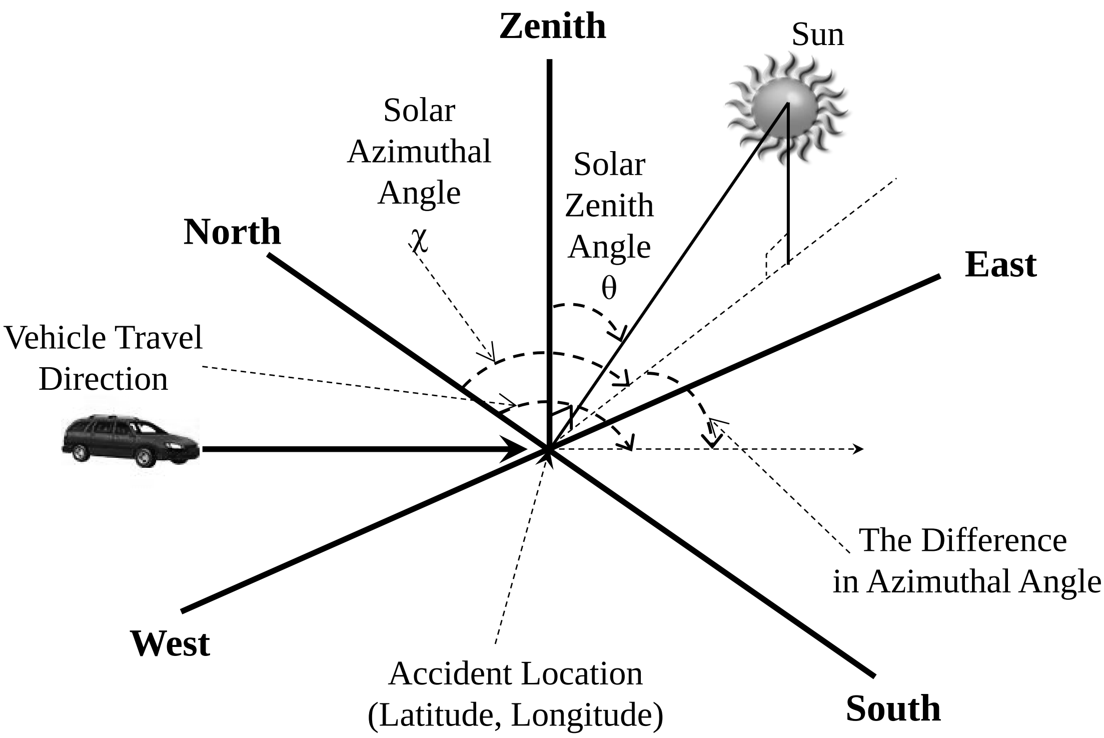

Figure 2. Solar position at the accident spot

Formulae for calculating the solar zenith angle and azimuthal angle are explained here. This method was showed by Murakami, T. (2010). Solar declination (δ) and hour angle (t) are indices representing the solar position on the celestial sphere. The north celestial pole is expressed as +90 degrees and the south celestial pole is expressed as -90 degrees in solar declination (δ). Hour angle (t) is the angle between the celestial meridian and the great circle that includes solar position and both celestial poles. The position of the sun relative to the earth was estimated by calculating solar declination (δ) and hour angle (t). The solar zenith angle (θ) at the accident spot is determined by latitude and longitude, and the solar zenith angle (θ) was calculated in order to use the solar declination (δ), hour angle (t) and latitude and longitude at the accident spot, as shown in Formula (1). The solar azimuthal angle (θ) at the accident spot is also determined by latitude and longitude, so as a first step in calculating the solar azimuthal angle (θ), the sine and cosine of χ were calculated using solar declination (δ), hour angle (t) and solar zenith angle (θ) from Formulae (8) and (9). The values of sine and cosine of χ are then

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

where

θ : solar zenith angle (rad)
δ : solar declination (rad)
φ : latitude (deg., at accident spot)
λ : longitude (deg., at accident spot)
t : hour angle (deg.)

where,

$$\delta = 0.006918 - 0.399912\cos A + 0.070257\sin A - 0.006758\cos(2A) + 0.000907\sin(2A) - 0.002697\cos(3A) + 0.00148\sin(3A) \quad (2)$$

$$A = \frac{2\pi J}{365} \quad (3)$$

where,

J: day of the year (Julian day)

$$t = 15\frac{\pi}{180}(TST - 12) \quad (4)$$

$$TST = MST + ET \quad (5)$$

$$MST = GMT + \frac{\lambda}{15} \quad (6)$$

$$ET = (0.000075 + 0.001868\cos A - 0.032077\sin A - 0.014615\cos(2A) - 0.040849\sin(2A))\frac{12}{\pi} \quad (7)$$

where,

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

$$\sin\chi = \cos\delta\frac{\sin t}{\cos\theta} \quad (8)$$

$$\cos\chi = \frac{-\cos\varphi\sin\delta + \sin\varphi\cos\delta\cos t}{\sin\theta} \quad (9)$$

The calculated values of $\sin\chi$ and $\cos\chi$ are classified into cases, and χ_1 and χ_2 are calculated as follows.

$\cos\chi<0$, $\chi_1=2\pi-\chi$
$\cos\chi>0$ & $\sin\chi<0$, $\chi_1=3\pi+\chi$
If $\cos\chi$ and $\sin\chi$ do not fit the two above-mentioned conditions then $\chi_1=\pi+\chi$

where,

$\chi_1>2\pi \quad \chi_2=\chi_1-2\pi$

If χ_1 is less than 2π, then the calculated χ_1 is the solar azimuthal angle. If the calculated χ_1 is more than 2π, then the solar azimuthal angle is $\chi_1-2\pi$, which is equal to χ_2. Therefore, either of the calculated χ_1 or χ_2 is the solar azimuthal angle.

3.3 Analysis Method

The traffic accident database consisted of the 134,339 injury accidents that were reported in Chiba Prefecture from 2007 to 2011. At first, the solar position at the accident time and spot was calculated for each accident by applying Formulae (1) to (9). Accidents in which the first vehicle concerned was missing were excluded, such as hit-and-run accidents. The analysis addressed the 125,332 accidents in which the first vehicle concerned was larger than a moped.

Excluding nighttime accidents (i.e., those in which the solar zenith angle exceeded 90 degrees) and accidents that did not occur in fine weather, 57,814 accidents were analyzed. Sun glare was regarded as a possible causal factor in these accidents. Nighttime injury accidents and accidents that occurred in weather that was not fine were used as control accident data. Daytime injury accidents and accidents in fine weather were classified as being influenced by sun glare or not, using the position of the sun relative to the vehicle as a threshold. The characteristics of traffic accidents to which sun glare was a contributing factor were analyzed by logistic regression analysis, and the sun glare's degree of contribution to traffic accident occurrence was estimated.

The orientations of roads do not depend on solar position, and most routes have ups and downs, so the vehicle travel direction does not depend on the solar azimuthal angle. The vehicle travel direction and the solar azimuthal angle are mutually independent.

4. RESULTS

4.1 Analysis by Solar Azimuthal Angle

Each accident datum was assigned a code of daytime or nighttime, according to the accident occurrence time. As mentioned above, it is possible to calculate the solar position at the accident occurrence time, and 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.

To show the position of the sun relative to the vehicle travel direction, the difference in azimuthal angle between the sun and the travel direction of the first vehicle concerned was defined as shown in Figure 2. 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

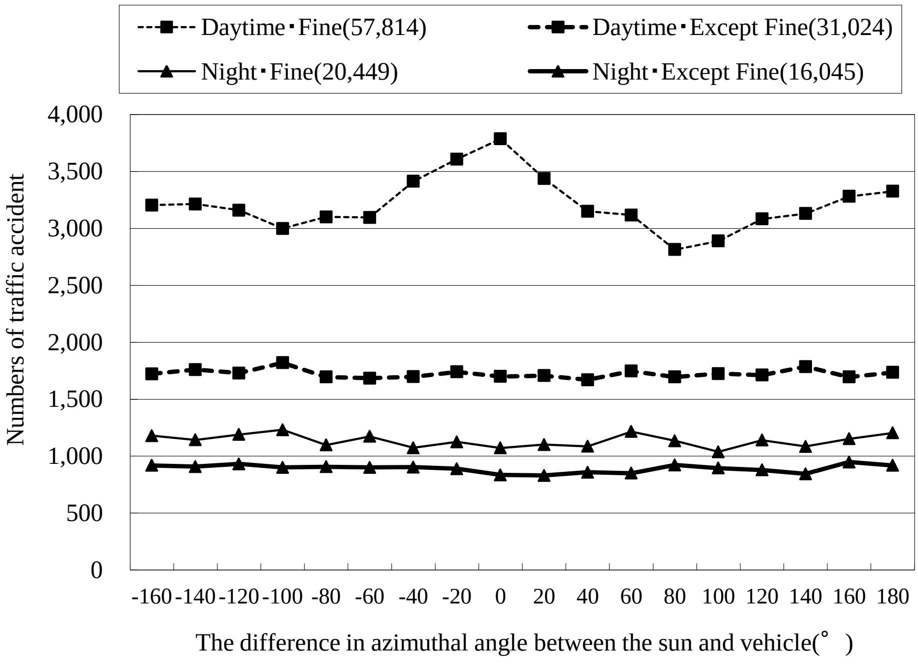

Figure 3. Numbers of traffic accidents vs. difference in azimuthal angle between the sun and the vehicle travel direction (Chiba-Pref., 2007～2011)

than −180 degrees, then 360 degrees is added to that difference. And if the difference in azimuthal angle exceeds 180 degrees, then 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 3, traffic accidents tend to occur at a higher rate when the sun is in front of the vehicle than when the sun is at other positions. As a control, Figure 3 shows data for nighttime and unfine weather accidents; the accident numbers are largely independent of the differences in azimuthal angle between the sun and vehicle travel direction.

The vehicle travel direction and the solar azimuthal angle are mutually independent. Because the difference in azimuthal angle between the sun and the vehicle indicates the position of the sun relative to the vehicle travel direction, the frequency of occurrence of the difference in azimuthal angle between the sun and the vehicle travel direction should be the same for any azimuthal angle. The frequency of occurrence of the difference in azimuthal angle for each 20-degree range should be the same as that for any other 20-degree range. As was found in previous studies, we can say that sun glare tends to be a factor contributing to accidents during daytime in fine weather.

4.2 Analysis by Solar Zenith Angle

Solar zenith angle at accident spots varies with season and time of day. The frequency of occurrence of solar zenith angle by season for vehicle drivers is not constant for each 10-degree range. Traffic accidents in Chiba Prefecture were analyzed in this paper, so solar zenith angle at the Chiba Prefectural Headquarters was defined as the representative value for Chiba Prefecture. Solar positions at every spot in Chiba Prefecture at the same time are not so different. So the frequency of occurrence of solar zenith angles for vehicle drivers at Chiba Prefectural Headquarters for one year was calculated.

Table 1. Cumulative hours in a year for each range of solar zenith angle at Chiba Prefectural Headquarters

Solar Zenith Angle (Degrees)	Spring (Mar～May)	Summer (Jun～Aug)	Autumn (Sep～Nov)	Winter (Dec～Feb)	Cumulative hours per Solar Zenith Angle	Percentage of Cumulative hours
10～20	47.3	145.3	0.0	0.0	192.6	2.2
20～30	130.2	196.2	9.4	0.0	335.7	3.8
30～40	182.5	164.8	89.0	0.0	436.2	5.0
40～50	197.4	154.0	157.6	44.3	553.3	6.3
50～60	164.0	152.2	244.7	239.1	799.9	9.1
60～70	156.0	152.7	192.4	265.3	766.5	8.7
70～80	154.1	155.8	167.2	190.1	667.2	7.6
80～90	155.4	161.7	157.5	168.5	643.0	7.3
More than 90	1021.1	925.4	1166.3	1252.7	4365.5	49.8
Total	2208	2208	2184	2160	8760	100.0

To apply Formulae (1) to (9), solar positions every two minutes at the Chiba Prefectural Headquarters were calculated. As shown in Table 1, the calculated solar zenith angles were aggregated to determine the frequency of occurrence of solar zenith angle according to season. Using the combined percentage of time per solar zenith angle, daytime traffic accident rates during fine weather according to solar zenith and azimuthal angle were calculated. Solar azimuthal angle was broken into 90-degree quadrants: “Front 90 degrees” is the forward quadrant extending 45 degrees left and right of the travel direction, “rear 90 degrees” is the rearward quadrant extending 45 degrees left and right of a line opposite to the travel direction, and “left 90 degrees” and “right 90 degrees” are the respective leftward and rightward quadrants. Moreover, numbers of daytime traffic accidents in fine weather were aggregated according to solar zenith and azimuthal angles. And traffic accident rates (Ar) according to the frequency of occurrence of solar zenith and azimuthal angle were calculated by using Formula (10). It is difficult to calculate fine weather in daytime by using weather data, because precise weather observation data are not available. So the “fine weather rate” was calculated by using weather items of daytime accident data.

$$\mathrm{Ar} = \frac{\mathrm{An}}{1{,}826 \times \mathrm{ZAr} \times \mathrm{Fr}} \qquad (10)$$

where,

Ar: traffic accident rate according to the frequency of occurrence of each range of solar zenith and azimuthal angle (accidents / 24 hours of fine weather)

An: numbers of traffic accidents during fine weather according to each range of solar zenith and azimuthal angle

ZAr: frequency of occurrence of solar zenith angle

Fr: fine weather rate (accidents during fine weather / all accidents)

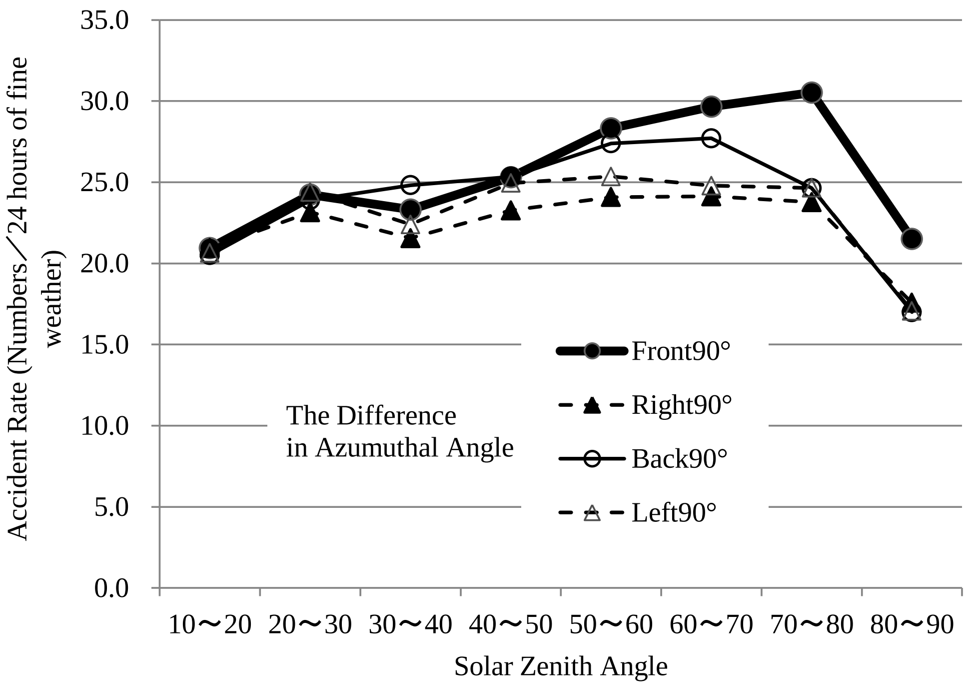

Figure 4. Traffic accident rates (accidents / 24 hours of fine weather) vs. solar zenith and azimuthal angle (Chiba-Pref., 2007～2011)

Figure 4 plots traffic accident rates vs. the solar zenith and azimuthal angle ranges calculated using Formula (10). When the sun is to the left or right of the first vehicle concerned, traffic accident rates do not increase with increases in solar zenith angle. However, when the sun is in front of the first vehicle concerned, traffic accident rates greatly increase with increases in the angles. When the angles start to exceed 80 degrees, traffic accident rates decrease, mainly because the sun is near the horizon. So, it is assumed that the drivers of the first vehicle concerned were affected more adversely by sun glare when the solar zenith angle was from about 50 to 80 degrees and the sun was in front of the first vehicle concerned. In contrast, the drivers of the first vehicle concerned were not affected by sun glare when the sun was near the horizon.

4.3 Logistic Regression Analyses for Multifactor Accident Analysis

4.3.1 Concept of the Analyses

According to FIGURE 3, the numbers of traffic accidents increase when the difference in azimuthal angle between the sun and vehicle is between about -45 degrees and 45 degrees. According to FIGURE 4 of Front 90 degrees, traffic accident rates are higher when the solar zenith angle is more than 45 degrees. So the difference in angle between the sun and vehicle in three dimensional spaces is less than 45 degrees, the numbers of traffic accidents increase. That is to say, the numbers of traffic accidents increase when the sun is located within 90 degrees of first vehicle's concerned viewing angle. As shown in FIGURE 5, the viewing angle is defined as the angle within 45 degrees left and 45 degrees right of a line extending straight from vehicle travel direction, and the angle within 45 degrees of a line extending straight from vehicle travel direction.

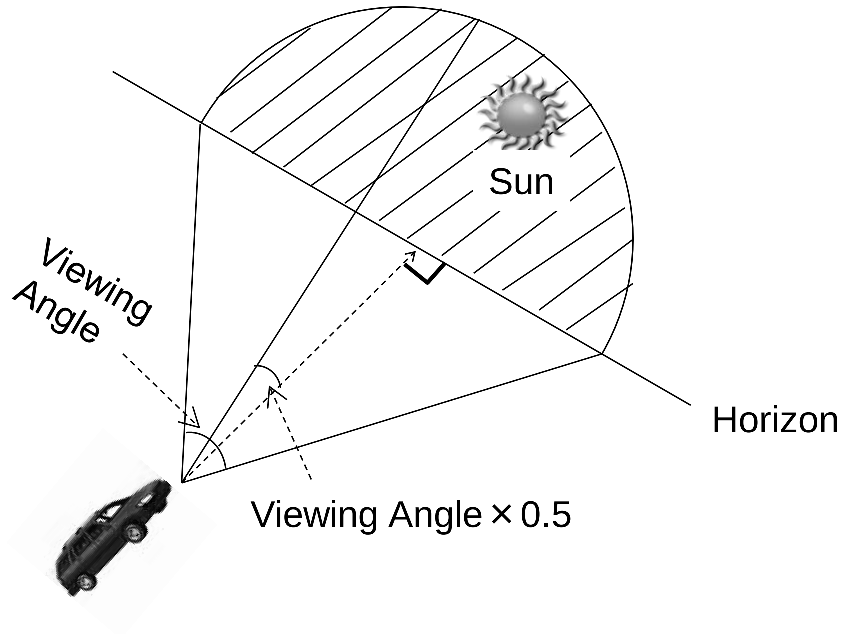

Figure 5. Viewing Angle

Daytime traffic accidents during fine weather were extracted. Of these accidents, the 10,352 in which the viewing angle of the sun relative to the vehicle was less than 90 degrees were regarded as sun-glare-related, and the other 47,462 accidents were regarded as sun-glare-unrelated.

To determine which kinds of accidents are sun-glare-related, logistic regression analyses were carried out, with viewing angle as the dependent variable and certain items recorded in traffic accident data as the independent variables. The independent variables shown in Table 2 were extracted for analysis. To clarify which kinds of attributes were affected by sun glare, gender and age-group were selected as the independent variables. Road traffic condition and effect of sun glare may have relation, so, as representative indexes of road traffic condition, road type and vehicle turning direction were selected as independent variables. Furthermore, sunshine in winter is more dazzling than that in summer on Pacific Ocean side of Japan which locates Chiba Prefecture. So season was selected as independent variable. Driving behavior and effect of sun glare may have relation, so accident type and vehicle speed were selected as independent variables.

Items of gender, age-group and road type were utilized in all logistic regression analyses concerning co-relations of these independent variables. And characteristic of traffic accidents that the viewing angle of the sun relative to the vehicle was less than 90 degrees were analyzed to use vehicle turning direction and accident type for independent variables at first. Vehicle speed and vehicle turning direction are closely correlated, so traffic accidents that vehicle turning direction is straight ahead were selected to search effect of vehicle speed on these accidents. And logistic regression analysis was carried out to use accident type and vehicle speed for independent variables. Cumulative hours for each range of solar zenith angle are dependent on the seasons, so two types of accidents were extracted. One type is accidents in which the viewing angle of the sun relative to the vehicle travel direction is less than 90 degrees, and the other type is accidents in which the viewing angle of the sun is less than 90 degrees when the vehicle travel direction is rotated 180 degrees azimuthally. And logistic regression analysis was carried out to use vehicle turning direction, accident type and season for independent variables.

Table 2. Independent variables and their categories

Independent Variable		Category
Attribute	Gender	Male / Female
	Age-Group	24 and less / 25～64 / 65 and over
Road Traffic Condition	Road Type	Signalized Intersection / Unsignalized Intersection / Near Intersection / Non-Intersection
	Vehicle Turning Direction	Straight Ahead / Right Turn / Left Turn / Stop
	Season	Spring(Mar～May) / Summer(Jun～Aug) / Autume(Sep～Nov) / Winter(Dec～Feb)
Driving Behavior	Accident Type	Heavy Vehicle / Passenger Car / Two-wheeled / Bicycle / Pedestrian
	Vehicle Speed(km/h)	10 or less / 20 or less / 30 or less / 40 or less / more than 40

4.3.2 Logistic Regression Analysis by Accident Type

Except in the case of single-vehicle accidents, traffic accidents generally have two vehicles: the first vehicle concerned (i.e., that of the driver who is primarily responsible for causing the accident) and the second vehicle concerned. It is possible to analyze accidents regarding independent variables of first vehicle concerned and second vehicle or person concerned. These two are independent of each other, so it is difficult to determine how sun glare affects them by applying logistic regression analysis. So, type of accident was defined as a new item in this study. Vehicle or person concerned was divided into the five categories of heavy vehicle, passenger car, two-wheeled vehicle, bicycle and pedestrian. A heavy vehicle in this study is one whose gross weight exceeds 5 tons. Accident type is divided into the five categories shown in Table 3 by combining first vehicle concerned and second vehicle or person concerned. Independent variables were extracted concerning correlations between items. Logistic regression analysis was carried out to clarify the effect of sun glare on accidents. Viewing angle is the dependent variable and gender, age group, road type, accident type and vehicle turning direction are independent variables in this analysis.

Table 3. Accident types (The first vehicle concerned is a heavy vehicle, a passenger car or a two-wheeled vehicle.)

Accident Type	Definition of Accident Type
Heavy Vehicle	Heavy Vehicle Alone, Heavy Vehicle to Heavy Vehicle or Passenger Car
Passenger Car	Passenger Car Alone, Passenger Car to Passenger Car
Two-wheeled Vehicle	Except PedestrianAccident and Bicycle Accident, At least One of First or Second Vehicle Concerned is Two-Wheeled Vehicle
Bicycle	Second Vehicle Concerned is Bicycle
Pedestrian	Second Person Concerned is Pedestrian

The results of this analysis are shown in Table 4. The bigger are the parameters, the greater is sun glare as a factor contributing to accidents. Parameters of attributes like gender and age group are not different. This means that drivers of only a specific gender or age group were not affected adversely by sun glare, but drivers of all genders or age groups were adversely affected equally. But parameters of road type, accident type and vehicle turning direction differ depending on whether there is sun glare. This means that vehicle drivers in specific traffic conditions were affected more adversely by sun glare than those in all other traffic conditions. The parameters of pedestrian accident, bicycle accident and accident at signalized intersection are particularly large. That is to say, sun glare tends to be a particularly strong contributing factor with respect to these accidents. Right-turning accidents have the same tendency.

The reason for this tendency might be that drivers of four-wheeled or two-wheeled vehicles have a heavier task load at signalized intersections than at unsignalized intersections and non-intersections. Another reason might be that road users like cyclists or pedestrians are smaller, so that sun glare tends to cause vehicle drivers to not see them.

Table 4. Logistic regression analysis for accident type (Chiba-Pref., Daytime, Fine, 2007～2011)

Independent Variable		N	Parameter	T-Value	Significant
Gender	Male	39,219	0.014	0.57	
	Female (Dummy)	18,595	0	0	
Age	65 and Over	9,919	-0.027	0.63	
	25～64	41,386	-0.027	0.76	
	24 and Less (Dummy)	6,509	0	0	
Road Type	Signalized Intersection	8,598	0.333	9.96	**
	Unsignalized Intersection	17,963	0.056	2.00	*
	Near Intersection	6,375	0.010	0.26	
	Non Intersection (Dummy)	24,878	0	0	
Vehicle Turning Direction	Stop	676	-0.300	2.64	**
	Left Turn	7,831	-0.031	0.87	
	Right Turn	11,322	0.089	2.95	**
	Straight Ahead (Dummy)	37,985	0	0	
Accident Type	Heavy Vehicle	2,151	0.051	0.84	
	Two-wheeled Vehicle	8,714	-0.002	0.05	
	Bicycle	15,277	0.356	12.20	**
	Pedestrian	6,114	0.433	12.12	**
	Passenger Car (Dummy)	25,558	0	0	
Constant			-1.74	43.36	

ρ^2(Likelihood Ratio)＝0.220, **1%, *5%

4.3.3 Logistic Regression Analysis by Vehicle Speed

The contribution of sun glare to accident occurrence, might depend on the speed of the first vehicle concerned, so logistic regression analysis to clarify the effect of sun glare on vehicle speed was carried out by using vehicle speed as independent variable. Vehicle speed is defined as the first vehicle's driving speed when the driver became aware of the risk of impending accident. For first vehicles turning left or right, or stopping, the vehicle speed was lower than that of those going straight. So 37,950 accidents in which the vehicle turning direction of the first vehicle concerned was straight ahead were extracted and logistic regression analyses were carried out on these data.

The results of this analysis are shown in Table 5. Independent variables like road type and accident type have the same tendencies as in Table 4. But the values of vehicle speed parameters are small, and these parameters have no significant differences among them. Furthermore, when the speed of the first vehicle concerned is more than 40 km/h, the value of vehicle speed parameter is not higher. Sun glare is less of a contributing factor in these accidents than in low-speed accidents. Thus, the rate of sun-glare-related accidents was not observed to increase with increases in vehicle speed.

Table 5. Logistic regression analysis for vehicle speed (Chiba-Pref., Daytime, Fine, 2007～2011)

Independent Variable		N	Parameter	T-Value	Significant
Gender	Male	26,211	0.017	0.57	
	Female (Dummy)	11,739	0	0	
Age	65 and Over	6,080	-0.030	0.58	
	25～64	27,001	-0.016	0.38	
	24 and Less (Dummy)	4,869	0	0	
Road Type	Signalized Intersection	2,937	0.254	4.98	**
	Unsignalized Intersection	9,493	0.066	1.84	
	Near Intersection	5,644	-0.014	0.34	
	Non Intersection (Dummy)	19,876	0	0	
Accident Type	Heavy Vehicle	1,910	0.051	0.77	
	Two-wheeled	3,395	0.008	0.15	
	Bicycle	7,354	0.282	7.45	**
	Pedestrian	4,013	0.338	7.63	**
	Passenger Car (Dummy)	21,278	0	0	
Vehicle Speed	10km/h or Less	11,156	0.028	0.55	
	20km/h or Less	8,519	0.082	1.54	
	30km/h or Less	7,352	0.053	0.98	
	40km/h or Less	6,851	0.059	1.09	
	More than 40km/h (Dummy)	4,072	0	0	
Constant			-1.77	28.59	

ρ^2(Likelihood Ratio)＝0.064, **1%, *5%

4.3.4 Logistic Regression Analysis by Season

It is said that sun glare tends to be worse in winter than in any other season. To show how sun glare contributes to accidents in winter, logistic regression analysis by season was carried out. As the culmination altitude of the sun depends on the season, the frequency of occurrence of each solar zenith angle differs by season. It is impossible to use all the data for accidents in daytime fine weather to evaluate the sun glare in winter, because the sun rising position varies by season. So, two types of accidents that occurred in daytime during fine weather were extracted. One type is accidents in which the viewing angle of the sun relative to the vehicle travel direction is less than 90 degrees, and the other type is accidents in which the viewing angle of the sun is less than 90 degrees when the vehicle travel direction is rotated 180 degrees azimuthally. Logistic regression analysis by season was carried out. Viewing angle is the dependent variable, and gender, age group, road type, accident type, vehicle turning direction and season were independent variables in this analysis.

The results are shown in Table 6. Independent variables other than season have the same tendencies as in Tables 4 and 5. As for season, the percentage of accidents in which the sun is in front of vehicle is higher in winter than in the other seasons. This indicates that sun glare had a greater affect on the accident occurrence in winter than in any other season. However, the parameter of winter is lower than those of signalized intersection, bicycle accident and pedestrian accident.

Table 6. Logistic regression analysis of season (Chiba-Pref., Daytime, Fine, 2007～2011)

Independent Variable		N	Parameter	T-Value	Significant
Gender	Male	13,261	-0.015	0.48	
	Female (Dummy)	6,232	0	0	
Age	65 and Over	3,176	0.167	2.96	**
	25～64	14,051	0.018	0.38	
	24 and Less (Dummy)	2,266	0	0	
Road Type	Signalized Intersection	3,241	0.225	4.87	**
	Unsignalized Intersection	6,010	0.001	0.02	
	Near Intersection	2,143	-0.058	1.18	
	Non Intersection (Dummy)	8,099	0	0	
Accident Type	Heavy Vehicle	692	0.174	2.18	*
	Two-wheeled	2,717	0.151	3.21	**
	Bicycle	5,277	0.578	14.52	**
	Pedestrian	2,211	0.616	12.32	**
	Passenger Car (Dummy)	8,596	0	0	
Vehicle Turning Direction	Stop	177	-0.070	0.45	
	Left Turn	2,621	0.019	0.39	
	Right Turn	3,885	0.190	4.55	**
	Straight Ahead (Dummy)	12,810	0.000	0	
Season	Autumn	5,060	-0.023	0.52	
	Winter	7,322	0.112	2.64	**
	Spring	3,757	0.007	0.14	
	Summer (Dummy)	3,354	0	0	
Constant			-0.26	4.36	

ρ^2(Likelihood Ratio)＝0.129, **1%, *5%

5. CONCLUSION

The analyses show that sun glare affects traffic accident occurrence. Analyses according to solar zenith and azimuthal angles found that the traffic accident rate increased when the viewing angle decreased to less than 90 degrees. Therefore, it was determined that sun glare was a greater contributing factor in traffic accidents in which the viewing angle of the sun and the first vehicle concerned was less than 90 degrees. Logistic regression analyses were carried out with the viewing angle of the sun and the first vehicle concerned as the dependent variable, and gender, age group, road type, accident type, vehicle turning direction and season as the independent variables.

In preceding studies (Hagita and Mori ;(2011)[2), 3), 4), 5)]), only one index like accident type and vehicle type affected by sun glare were used for the analysis, but in this study, many indexes were used as the independent variables to which kinds of attributes, road traffic conditions and driving behavior were affected by sun glare.

Considering these results comprehensively, it is concluded that sun glare makes the greatest contribution to traffic accidents in the cases of pedestrian accidents and bicycle accidents at signalized intersections. Sun glare was found to contribute slightly more to accidents by right-turning vehicles than to other turning directions; however, vehicle speed at the time of the accident was independent of sun glare. In winter, sun glare was found to contribute slightly to accidents.

In contrast, sun glare’s contribution to traffic accidents was not found to vary with driver attributes, such as gender and age group. This indicates that sun glare equally affects drivers of all attributes, rather than drivers with any particular attribute.

6. FUTURE DIRECTIONS

This research addressed sun glare in front of the first vehicle concerned. But as shown in Figure 3, the traffic accidents had occurred slightly more when the difference in azimuthal angle between the sun and the vehicle is near 180 degrees. Based on previous research(Hagita and Mori ;(2011)[3)]), the higher occurrence of accidents at azimuthal angles near 180 degrees was attributed to rear-end accidents. In that situation, the sun is behind the first vehicle concerned, and the higher occurrence of accident is attributed to the sun shining from behind the first vehicle concerned. In that case, it is assumed that the driver is dazzled by the sun causing a glare in the rear window of the preceding vehicle or in the back or side mirror of the first vehicle concerned. No clear conclusion on this has been reached.

All intersections are spots where road users are potentially blinded by the sun. This is because the direction of incident sunlight varies by time of day and season. So it is useless to implement remedial measures for the road traffic environment. However, wearing sunglasses on highway and expressway straightaways that are oriented east-west is a supposed accident countermeasure. To examine sunglasses as a measure against sun-glare-related accidents, the longitude and latitude of the accident spot and the vehicle travel direction should be added to items in the national traffic accidents database. By collecting these items nationwide, it will be possible to precisely analyze how sun glare contributes to traffic accidents on many routes.

Weather in the traffic accident database is divided into the five categories of fine, cloudy, rainy, foggy and snowy. The boundary between fine and cloudy is determined by the degree of overcast sky. Skies 80 percent overcast or more are cloudy. When the degree of cloudiness is less than 80 percent, the sun sometimes is covered with clouds. So progress of weather observation technology is needed.

The visibility of the sun relative to the vehicle depends on longitudinal slope, surrounding buildings and topography. So it is difficult to precisely calculate the traffic visual condition under the adverse effect of sun glare. By collecting these data on GIS, it may be possible to calculate solar position relative to the vehicle travel direction more precisely.

REFERENCES

Daniel, J., Byun, J. and Chien, S. (2009): Impact of Adverse Weather on Freeway Speeds and Flows, *TRB 2009 Annual Meeting* CD-ROM, 09-2837.

Hagita, K., Mori, K. (2011) Analysis of the Influence of Sun Glare on Traffic Accidents in Japan. *Journal of the Eastern Asia Society for Transportation Studies*, Vol.9, 1775-1785.

Hagita, K., Mori, K. (2011): Analysis of Traffic Accident Influenced by Sun Glare. *Journal of Japan Society of Civil Engineers (D3)*, 1055-1062. (in Japanese)

Hagita, K., Mori, K. (2011): Analysis of the Influence of Sun Glare on Pedestrian Accidents, *Papers of the 31st Japan Society of Traffic Engineers Annual Meeting*. CD-ROM, No.7. (in Japanese)

Hagita, K., Mori, K. (2011): Analysis by Vehicle Types of Traffic Accident Influenced by Sun Glare. *Summarized Papers, 2011 Society of Automotive Engineers of Japan Annual Congress (Autumn)*, 12-11, No.8. (in Japanese)

Institute for Traffic Accident Research and Data Analysis (ITATDA) Research Report (2002) Research on the Effect of Natural Disasters on Traffic Accident Occurrence. (in Japanese)

Jurado-Pina, R. and Pardillo-Mayora, J. M. (2009): Methodology to Predict Driver Vision Impairment Situations Caused by Sun Glare. *TRB 2009 Annual Meeting CD-ROM*, 09-1429.

Jurado-Pina, R., Pardillo-Mayora, J. M. and Jimenez, R. (2010): Methodology to Analyze Sun Glare Related Safety Problems at Highway Tunnel Exits, *Journal of Transportation Engineering*, No.6, 545-553.

Mitra, S. (2008): Investigating Impact of Sun Glare on Transportation Safety, *TRB 2008 Annual Meeting CD-ROM*, 08-2184.

Murakami, T. (2010): Methods for Calculating Solar Zenith Angle and Solar Azimuthal Angle, http://www.agr.niigata-u.ac.jp/~muratac/. (in Japanese)