ANALYSIS OF THE INFLUENCE OF SUN GLARE ON BICYCLE OR PEDESTRIAN ACCIDENTS WITH TURNING VEHICLE

Kenji HAGITA, Senior Researcher, Traffic Science Division, National Research Institute of Police Science, 6-3-1, Kashiwanoha, Kashiwa City, Chiba, 277-0882, Japan, Tel: +81-4-7135-8001, Fax: +81-4-7133-9187, E-mail: hagita@nrips.go.jp

Kenji MORI, Chief Traffic Science Division, National Research Institute of Police Science, 6-3-1, Kashiwanoha, Kashiwa City, Chiba, 277-0882, Japan, Tel: +81-4-7135-8001, Fax: +81-4-7133-9187, E-mail: mori@nrips.go.jp

ABSTRACT

This study aims to clarify the effect of sun glare on bicycle accident and pedestrian 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. Daytime traffic accidents that occurred during fine weather were extracted for analysis. Bicycle accident and pedestrian accident rates were found to be higher when the viewing angle was less than 90 degrees. Bicycle accidents and pedestrian accidents during daytime fine weather were extracted, and sun glare was found to contribute more to bicycle accidents and pedestrian accidents with left- or right-turning vehicles than with non-turning vehicles. Traffic accidents between turning vehicles and oncoming bicycles or pedestrians were much more frequent when the sun was in front of the turning vehicle. It is concluded that sun glare makes the greatest contribution to traffic accidents in cases of oncoming bicycles or pedestrians encountering turning vehicles. To prevent these accidents, it may be important to develop and equip the vehicle interior with devices to protect the driver from sun glare.

Keywords: Sun Glare, Accident, Bicycle, Pedestrian

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 road traffic conditions, so traffic safety measures against sun glare have been implemented.

One example is the sun visor that is installed on the 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 is 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 improved. However, sun glare still hinders road traffic safety: 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 (2011a, 2011b, 2011c, 2011d) 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 result suggests that sun glare is a causal factor in accidents. 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. But which types of bicycle accidents and pedestrian accidents had occurred more caused by sun glare is not clear. So, 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. This research aims to determine the types of bicycle accidents and pedestrian accidents to which sun glare contributes the most.

REVIEW

In studying how sun glare contributes to traffic accident occurrence in Japan, Hagita and Mori (2011a, 2011b) found that the traffic accident rate tended to be higher when the sun was in front of the vehicle. Regarding pedestrian accidents (2011c), they were found to occur with greater frequency than other types of accidents when the sun was in front of the vehicle. Accident black spots at which sun glare was found to contribute to an elevated rate of pedestrian accidents were not found in that paper. Regarding accidents broken down by vehicle type (2011d), 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 motorized two-wheeled vehicles when the sun was immediately in front of those vehicles. This is attributed to the fact that the viewing angle for drivers of motorized two-wheeled vehicles wearing full-face helmet is narrower than that of other vehicle drivers.

In an analysis of traffic accident data, sunset and sunrise times, and road travel directions in Arizona, USA, Mitra (2008) showed that traffic accident rates are higher at dusk and dawn than at other times. 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 one hour 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 the influence of sun glare on accident rates. Jurado-Pina, Pardillo-Mayora and Jimenez (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, Byun and Chien (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 meteorological phenomena, 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 rates of bicycle accidents and pedestrian accidents. The present study aims to extend these Japanese studies.

METHODS

Database of Traffic Accidents 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: the geographic coordinates of the accident spot, and the vehicle travel direction. The latter has never been included in the national traffic accident database in Japan, and the former was not included until 2012. 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. 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.

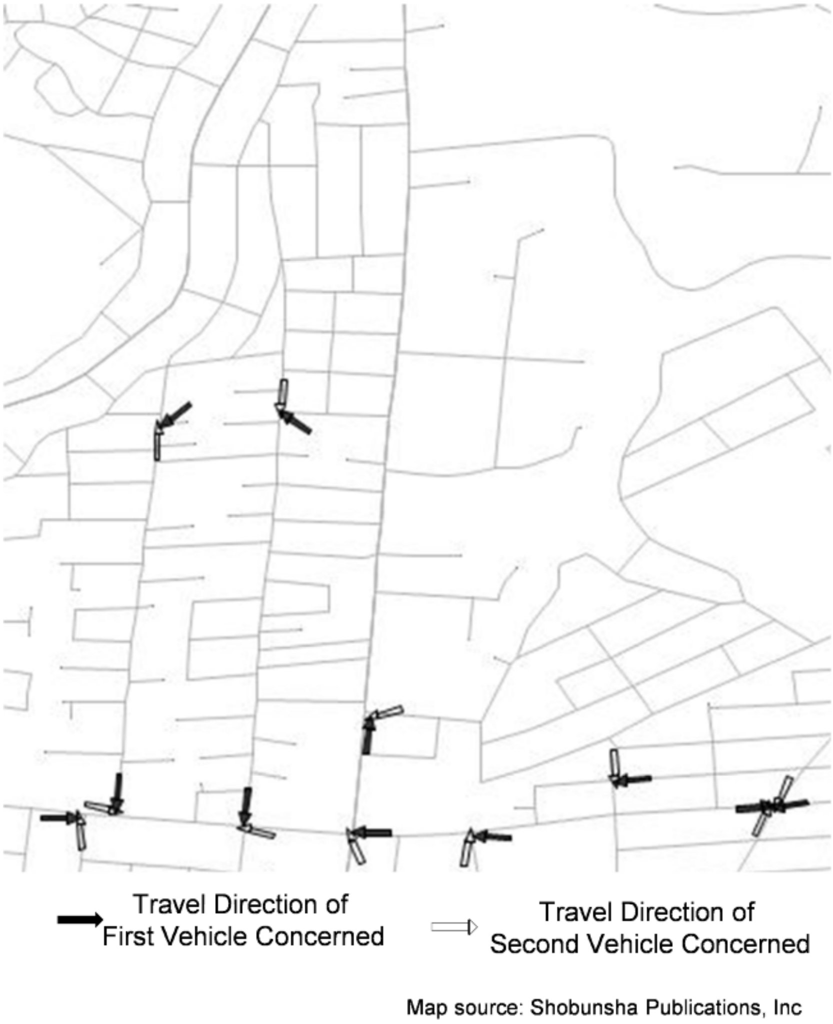

Figure 1 – GIS representation of traffic accidents in Chiba, including vehicle travel direction

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.

Formulae for calculating the solar zenith angle and azimuthal angle are explained here. 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

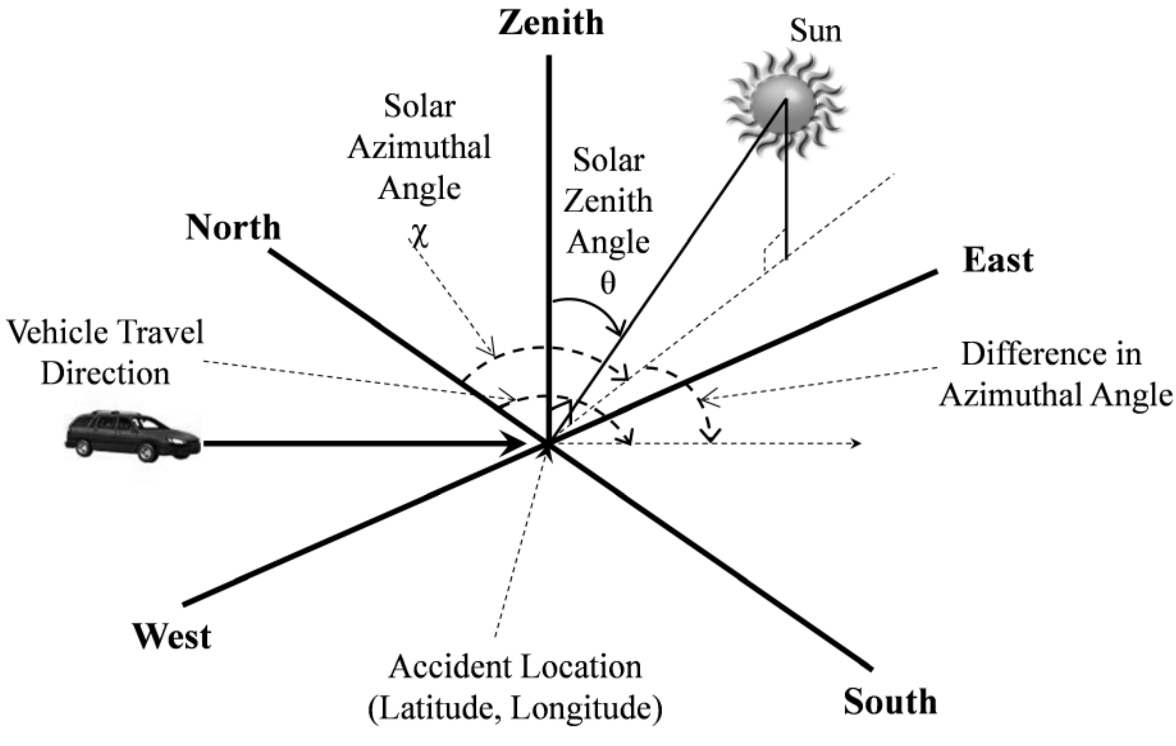

Figure 2 – Solar position at the accident spot

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

where

θ: solar zenith angle (rad)

δ: solar declination (rad)

φ: latitude of accident spot (deg.)

λ: longitude of accident spot (deg.)

t: hour angle (deg.)

where,

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

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

where,

J: day of the year (Julian day)

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

$$\mathrm{TST} = \mathrm{MST} + \mathrm{ET} \quad (5)$$

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

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

where,

TST: true solar time

MST: mean solar time (local time)

GMT: Greenwich Mean Time

ET: equation of time

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

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

The calculated values of sinχ and cosχ are classified into cases, and χ_1 and χ_2 are calculated as follows.

Cosχ<0, $\chi_1=2\pi-\chi$

Cosχ>0 & sinχ<0, $\chi_1=3\pi+\chi$

If cosχ and sinχ 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.

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 traffic accidents in fine weather were classified according to the type vehicle or person concerned. Bicycle accidents and pedestrian accidents were extracted, and the characteristics of these accidents to which sun glare was a contributing factor were analyzed, and the sun glare's degree of contribution to these 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.

RESULTS

Analyses by Solar Azimuthal Angle

Analysis by brightness

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 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 the 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.

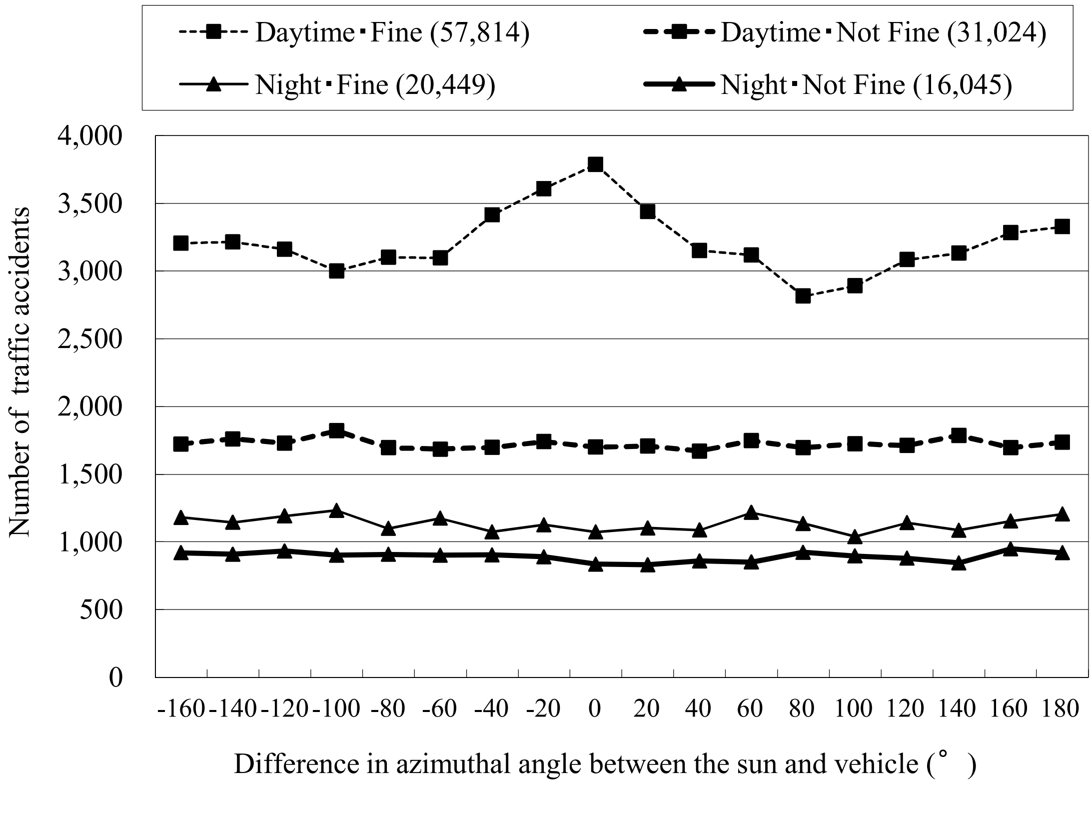

Figure 3 – Numbers of traffic accidents vs. difference in azimuthal angle between the sun and the vehicle travel direction (Chiba-Pref., 2007～2011)

Analysis by accident type

To show how sun glare factors relate to bicycle accident and pedestrian accident occurrence, the accident type was defined as a new item in this study. Vehicle or person concerned was divided into the five categories of heavy vehicle, passenger car, motorized two-wheeled vehicle, bicycle and pedestrian. A heavy vehicle here is one whose gross weight exceeds 5 tons. The accident types were determined by the type of car or person concerned and classified into five types. These types and their definitions are shown in Table 1.

Table 1 – Accident types (The first vehicle concerned is a heavy vehicle, a passenger car or a motorized two-wheeled vehicle.)

Accident Type	Definition
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 pedestrian accident and bicycle accident, First and/or second vehicle concerned is mortorized two-wheeled vehicle
Bicycle	Second vehicle concerned is bicycle
Pedestrian	Second person concerned is pedestrian

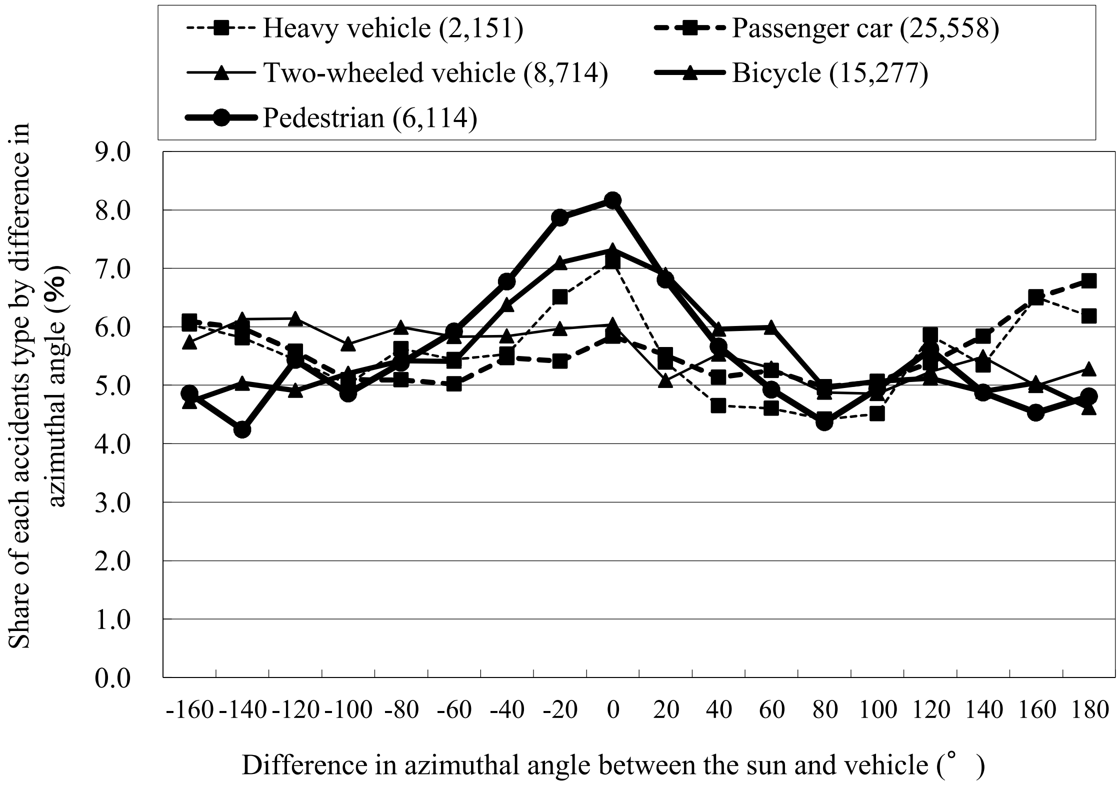

Figure 4 – Share of each accident type of traffic accidents vs. difference in azimuthal angle between the sun and the vehicle travel direction (fine, daytime)

Figure 4 shows the share of each accident type vs. the difference in azimuthal angle between the sun and the vehicle travel direction. Bicycle accidents and pedestrian accidents tend to occur at higher rates than the other types of accidents when the sun is in front of the vehicle. We can say that sun glare tends to have a particularly great contributing effect to bicycle accidents and pedestrian accidents during daytime fine weather.

Analysis of Bicycle Accidents and Pedestrian Accidents 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.

To apply Formulae (1) to (9), solar positions every two minutes at the Chiba Prefectural Headquarters were calculated. As shown in Table 2, 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 bicycle accident and pedestrian 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 accidents in fine weather were aggregated according to solar zenith and azimuthal angles. 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 determine 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 the daytime accident data.

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

where,

Ar: bicycle accident and pedestrian 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 bicycle accidents and pedestrian accidents during fine weather for 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)

Table 2 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	2208.0	2208.0	2184.0	2160.0	8760.0	100.0

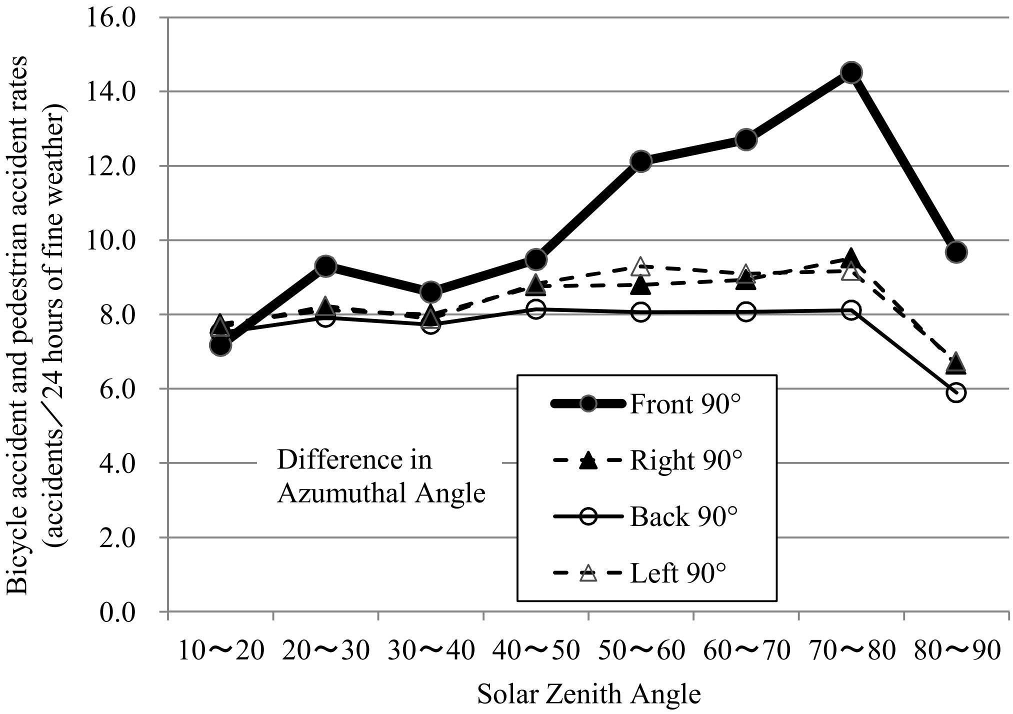

Figure 5 – Bicycle accident and pedestrian accident rates (accidents / fine 24 hours) according to solar zenith and azimuthal angle (fine, daytime)

Figure 5 plots bicycle accident and pedestrian accident rates vs. the frequency of occurrence of the solar zenith and azimuthal angle ranges calculated using Formula (10). When the sun is to the left, right and back 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 their vehicle. In contrast, the drivers of the first vehicle concerned were not affected by sun glare when the sun was near the horizon.

Analysis of Bicycle Accidents and Pedestrian Accidents by Vehicle Turning Direction

Definition of Turning Direction

As shown in Figure 6, vehicle travel direction is recorded by using one number from (1) to (4) as the origin of the first vehicle concerned, one number from (5) to (8) as the origin of the pedestrian, another number from (1) to (4) as the destination of the first vehicle concerned and another number from (5) to (8) as the destination of the pedestrian. The origin of first vehicle concerned is (1), in principle, although if an off-street space like parking is the origin of the first vehicle concerned, then origin of that vehicle becomes (2). In cases in which the origin of the first vehicle concerned was (2), the number (1) was substituted for the sake of convenience. The relative positions of the first vehicle concerned and the second vehicle concerned were converted accordingly. From this, left-turns of the first vehicle concerned are described as (1)(2), right turns as (1)(4), and straight ahead movement and backward movement or U-turns as (1)(3) or (1)(1).

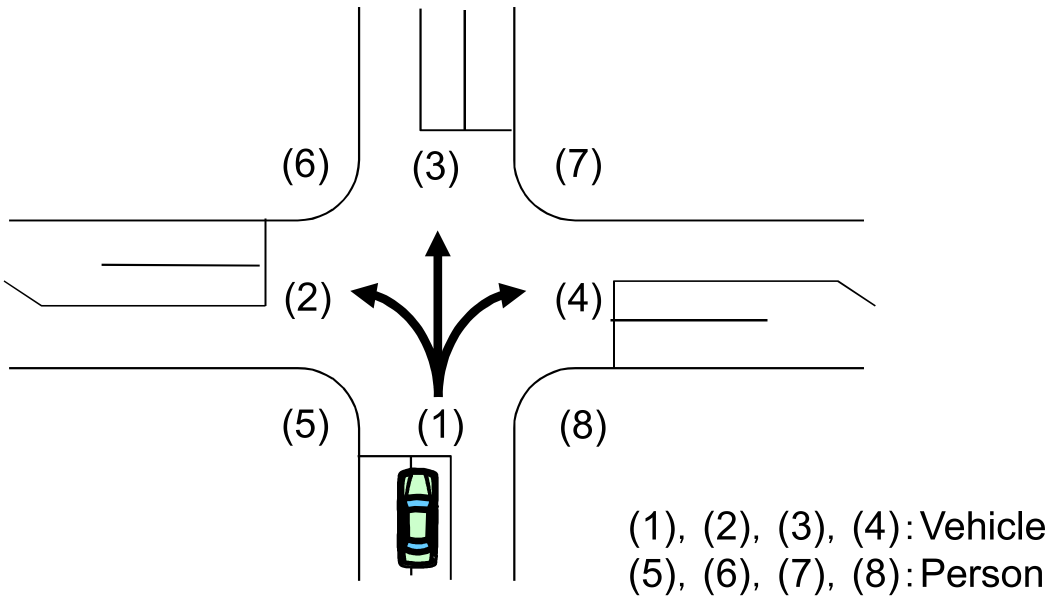

Figure 6 – Representation of turning direction

Analysis by Vehicle Turning Direction

According to results of Figures 3, 4 and 5, the accident rate gradually increases with decreases in the viewing angle of the sun and first vehicle concerned below 90 degrees. Figure 7 shows number of bicycle accidents and pedestrian accidents of each solar zenith angle according to the difference in azimuthal angle between the sun and the vehicle. It shows that sun glare was not an influencing factor for bicycle accidents and pedestrian accidents when the solar zenith angle was less than 45 degrees. Therefore, accidents in which the difference in azimuthal angle between the sun and vehicle was less than 45 were excluded from next analysis.

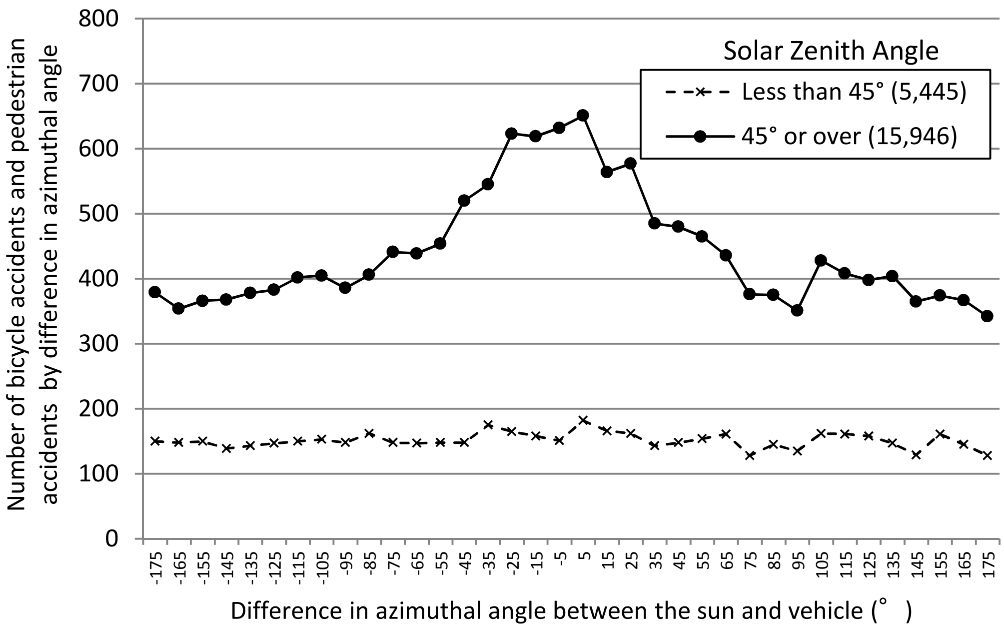

Figure 7 – Number of bicycle accidents and pedestrian accidents of each solar zenith angle according to the difference in azimuthal angle between the sun and vehicle (fine, daytime)

Figure 8 shows the share of bicycle accidents and pedestrian accidents of each vehicle turning direction according to the difference in azimuthal angle between the sun and vehicle. The accident rate was higher for each accident type when the sun was near the front of first vehicle concerned. The accident rate when the first vehicle concerned was turning left or right was much higher when the sun was located near the front of that vehicle. This was attributed to the sun suddenly coming into view in front of the drivers of left- or right-turning vehicles. It is difficult for drivers of left- or right-turning vehicles to adjust to sun glare, so bicycle accidents and pedestrian accidents with left- or right-turning vehicles were more frequent when the sun was near the front of the first vehicle concerned.

These accidents peak for left-turning vehicles when the difference in azimuthal angle is about 25 degrees and for right-turning vehicles when the difference in azimuthal angle is about -25 degrees. According to previous studies (2011a, 2011b, 2011c, 2011d), the peaks are near 0 degrees. The reason why the peaks in this study are not 0 degrees is attributed to the methods of recording the travel direction. Vehicle travel direction is recorded to show the traffic accident situation on a digital map or intersection drawing, not to analyze the relative position of the sun and the first vehicle concerned. The method of recording left- or right-turning vehicles in traffic accidents at intersections is diagrammed in the JSTE (2002) guideline. To show left- or right-turning vehicle clearly in intersection drawings, the travel direction of the left-turning vehicle must be rotated clockwise and that of the right-turning vehicle must be rotated anticlockwise. For that reason, the peak for each was recalibrated as 0 degrees. So the travel direction of left-turning vehicles is rotated -20 degrees and that of right-turning vehicles is rotated 20 degrees for next analysis.

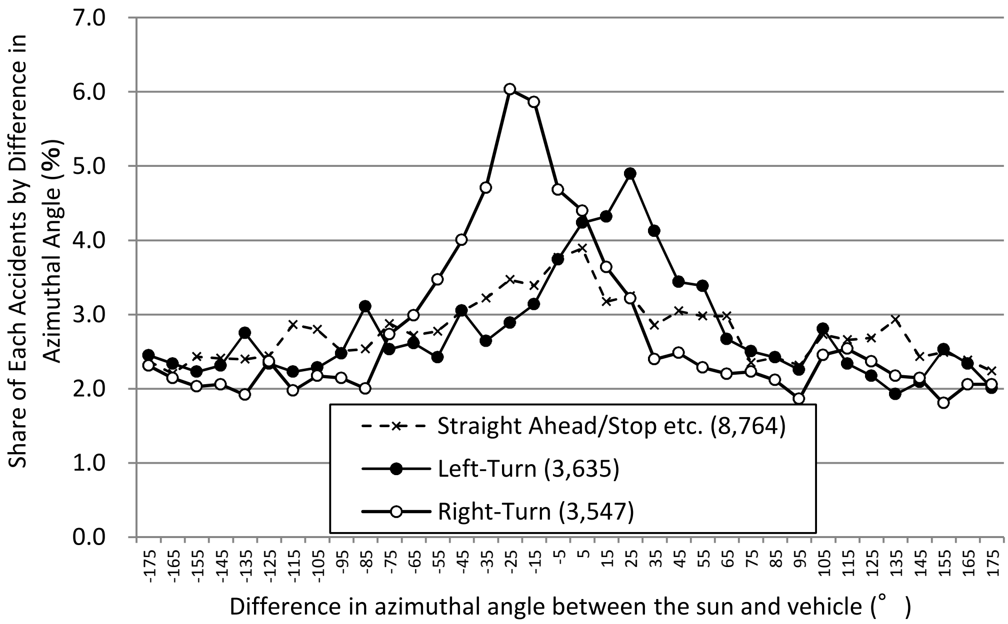

Figure 8 – Share of each vehicle turning direction for bicycle accidents and pedestrian accidents according to the difference in azimuthal angle between sun and vehicle (fine, daytime, solar zenith angle＞45°)

Analysis of Bicycle Accidents and Pedestrian Accidents with Turning Vehicles

To clarify the travel directions of the cyclists/pedestrians and the first vehicle concerned, bicycle and pedestrian travel directions to accident spot were defined by using the origin and destination scheme illustrated in Figure 6. Bicycle and pedestrian relative position were classified into the five categories of oncoming, back, left, right and other as shown Table 3.

Table 3 — Definition of bicycle and pedestrian relative position

First Vehicle Concerned	Bicycle		Pedestrian	
	Code of Relative Position	Definition of Relative Position	Code of Relative Position	Definition of Relative Position
(1)(2) (Left-Turning Vehicle)	(3)(1)	Oncoming	(6)(5)	Oncoming
	(1)(3)	Back	(5)(6)	Back
	(2)(4)	Left	(5)(8)	Left
	(4)(2)	Right	(8)(5)	Right
	Other	Other	Other	Other
(1)(4) (Right-Turning Vehicle)	(3)(1)	Oncoming	(7)(8)	Oncoming
	(1)(3)	Back	(8)(7)	Back
	(2)(4)	Left	(5)(8)	Left
	(4)(2)	Right	(8)(5)	Right
	Other	Other	Other	Other

Figures 9 to 12 show the numbers of each bicycle or pedestrian relative position in accidents with turning vehicles according to the difference in azimuthal angle between the sun and vehicle. These results show that accidents between turning vehicles and oncoming bicycles or pedestrians tended to be much more common when the sun was in front of the first vehicle concerned, i.e., behind the oncoming bicycle or pedestrian. When a right- or left-turning first vehicle crosses the path of an oncoming bicycle or pedestrian, if the sun is in front of that vehicle, the situation is very dangerous.

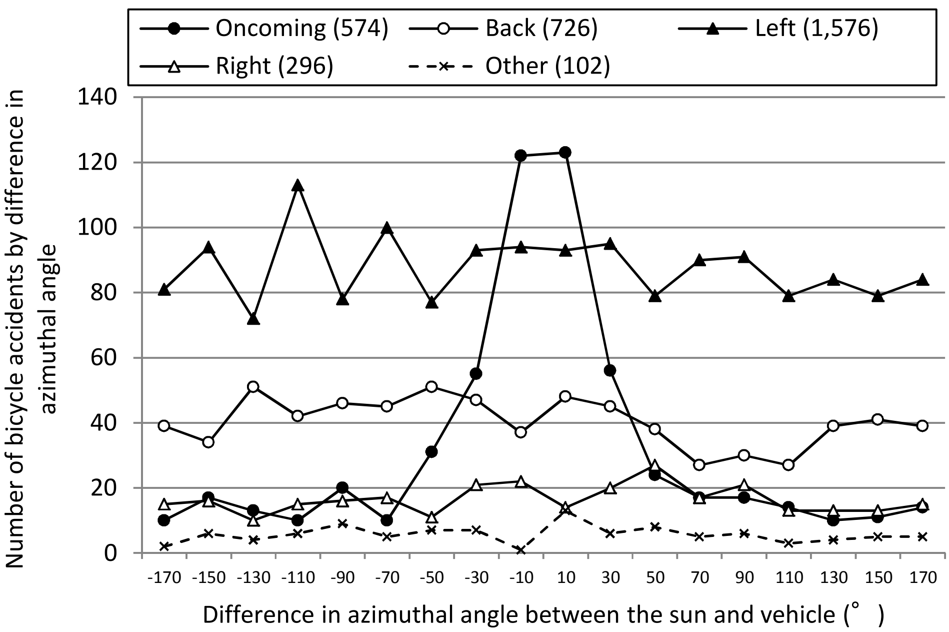

Figure 9 – Number of bicycle accidents by relative position according to the difference in azimuthal angle between the sun and vehicle (fine, daytime, solar zenith angle＞45°, left turn)

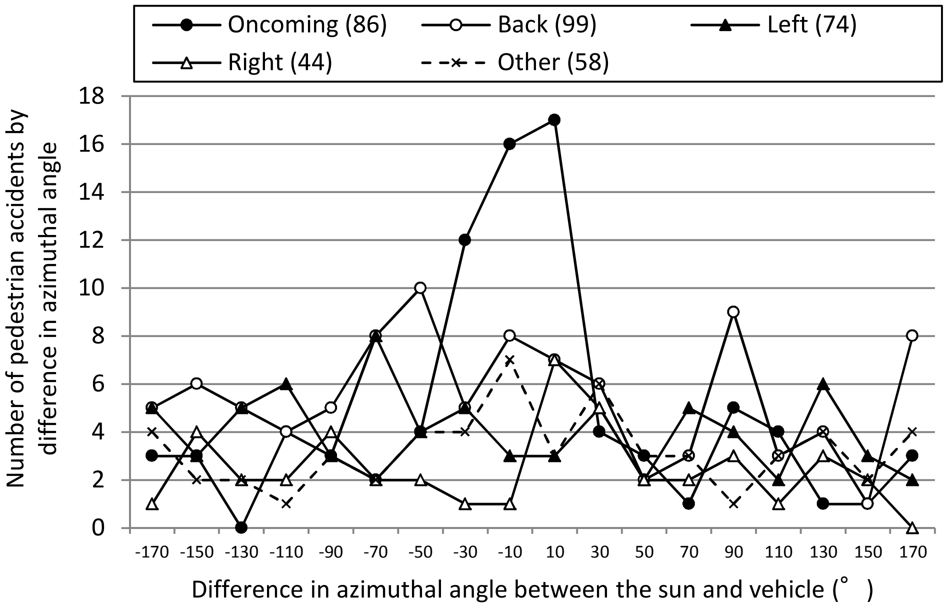

Figure 10 – Number of pedestrian accidents by relative position according to the difference in azimuthal angle between the sun and vehicle (fine, daytime, solar zenith angle＞45°, left turn)

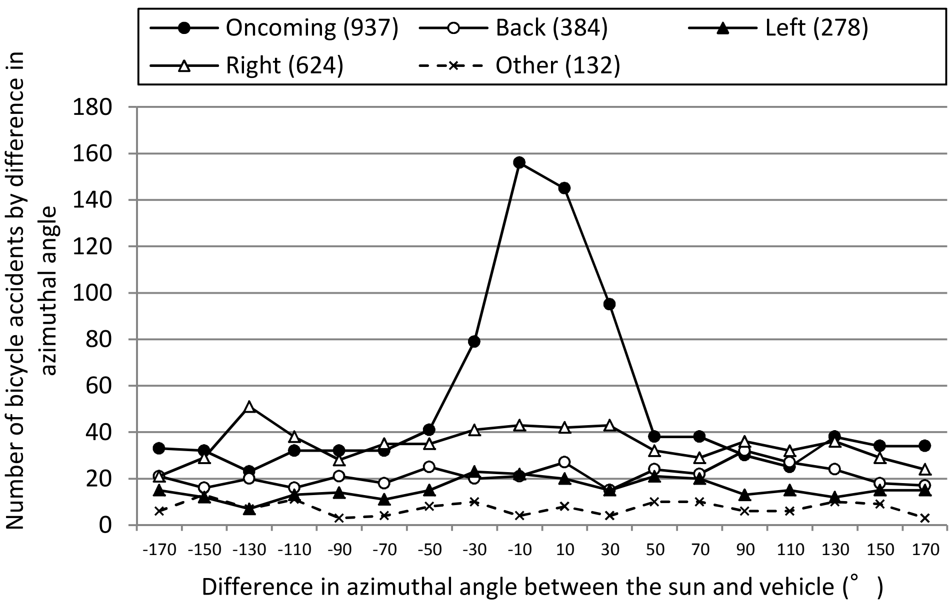

Figure 11 – Number of bicycle accidents by relative position according to the difference in azimuthal angle between the sun and vehicle (fine, daytime, solar zenith angle＞45°, right turn)

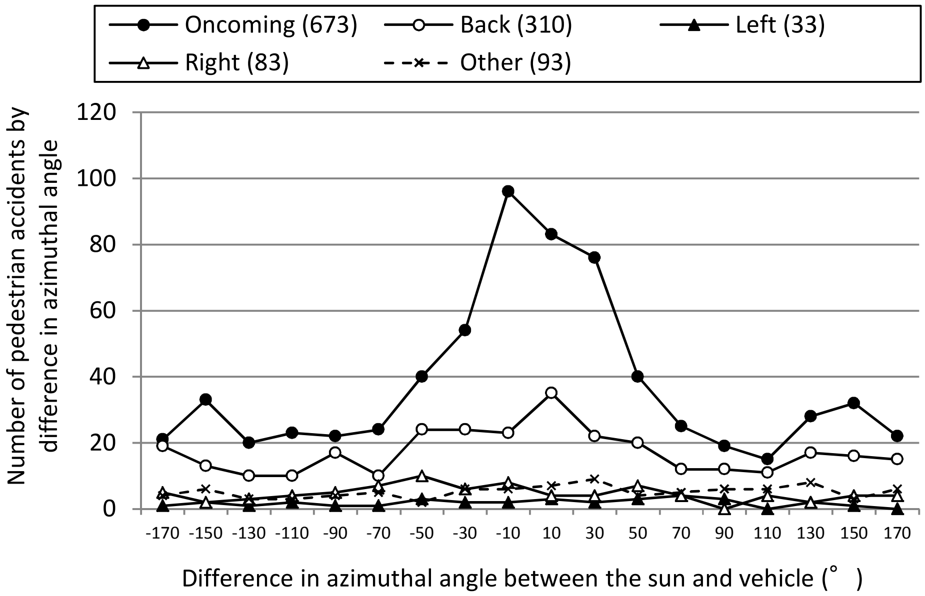

Figure 12 – Number of pedestrian accidents by relative position according to the difference in azimuthal angle between the sun and vehicle (fine, daytime, solar zenith angle＞45°, right turn)

CONCLUSION

The analyses show that sun glare is a greater factor in bicycle and pedestrian accidents than in other types of accidents. Analyses according to solar zenith and azimuthal angles found that the rates of bicycle accidents and pedestrian accidents increased with decreases in viewing angle below 90 degrees. Therefore, it was determined that sun glare was a greater contributing factor in bicycle accidents and pedestrian accidents in which the viewing angle of the sun and the first vehicle concerned was less than 90 degrees.

Sun glare was found to contribute more to bicycle and pedestrian accidents with vehicles turning left or right than with vehicles turning other directions. Among bicycle accidents and pedestrian accidents with turning vehicles, accidents in which the turning vehicle crashed with the oncoming bicycle or pedestrian were much more frequent when the sun was in front of the turning vehicle. For the sun to appear suddenly in front of the turning vehicle is very dangerous for turning driver. In light of the overall results, it is concluded that sun glare makes the greatest contribution to traffic accidents between oncoming bicycles or pedestrians and turning vehicles.

FUTURE DIRECTIONS

Turning vehicles have the potential to be blinded by the sun at any intersection, because the direction of incident sunlight varies by time of day and season. It is useless to implement remedial measures for the road traffic environment. A sun visor is one device to protect drivers from sun glare. According to this study, installing only a sun visor is not sufficient to protect drivers from sun glare. To protect drivers from sun glare, it is important to develop and install other devices in vehicle interiors.

Weather in the traffic accident database is divided into the five categories of clear, cloudy, rainy, foggy and snowy. The boundary between clear and cloudy is determined by how overcast the sky is. Skies 80% overcast or more are cloudy. Skies less than 80% overcast sometimes have clouds covering the sun. Progress of weather observation technology is needed.

The position of the sun relative to the vehicle depends on longitudinal slope, surrounding buildings and topography. 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.

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