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Development of Bicycle Throw Distance Estimation Model Based on Akaike Information Criterion Statistical Method

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Abstract

As the number of bicyclists is gradually increased, it is important to develop more accurate accident reconstruction model to response bicycle accidents with vehicles. There have been research works to reconstruct bicycle accident by using estimated vehicle impact speed and simulation methods. However, there are limitations that the models do not consider other significant factors that may affect bicycle throw distance including road friction, vehicle gross weight, engine hood types, and other factors. This study aims to develop the improved reconstruction model to estimate vehicle impact speed better. The results that utilize the statistical analysis and real accident data show that the road friction needs to be considered with vehicle impact speed to reconstruct the accident more accurately.

Keywords: Bicycle accident reconstruction model; Bicycle throw distance; Akaike Information Criterion

Introduction

Bicycle has emerged as an alternative transportation mode to mitigate environmental issues and transportation problems such as parking space shortage and traffic congestions [1]. The number of bicycle riders has gradually increased because of its healthy impact and conveniences. However, bicyclists are exposed to risk of accident, which is hit by motor vehicles and get fatality. In 2011, 677 bicyclists were killed and 52,000 were injured in motor vehicle accidents. The deaths account for 2.2% of all motor vehicle traffic fatalities (Traffic Safety Fact data, NHTSA's National Center for Statistics and Analysis). As indicated in Figure 1, the number of fatalities has increased since 2003; this implies that the number of bicyclists has increased since 2003. It would be obvious that bicycle is one of the most vulnerable transportation modes for safety on the road. There have been many efforts to plan and design bicycle paths and lanes to avoid collisions. However, the probability to be fatal accidents of collisions between vehicles and bicycles must be higher than any other modes.

The bicycle accident reconstruction model is important for collision investigation between bicycle and vehicles. Previous studies have shown that the pre-impact speed can be a factor to reconstruct the accident [2]. Most of the previous research is based upon limited impact factors such as vehicle impact speed and throw distance or simulation methods, the accuracy and interpretation of the model may have weaknesses themselves. Throw distance is defined as the distance between the point of impact and the point at which the bicycle first hits the ground [3]. The distance may be different as road friction according to weather conditions [4], for example, the vehicle's stop distance is longer under low road friction coefficients. Also the vehicle weight can influence to bicycle throw distance in the Momentum Theory [5].

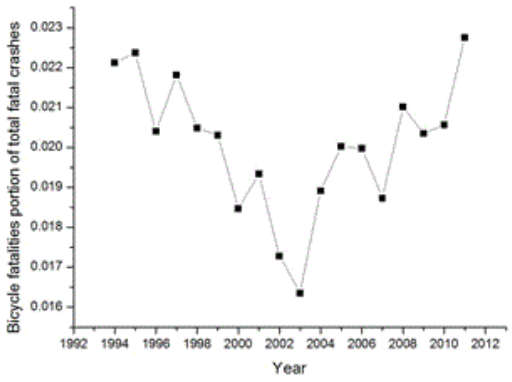

Figure 1: Bicyclist fatalities in traffic crashes statistics.

Therefore, the approach of this paper is to examine the throw distance according to relationships of vehicle impact speed, vehicle gross weight, road friction, and engine hood type with real accident data to develop a bicycle accident reconstruction model. The statistical method, Akaike Information Criterion (AIC), which is a measure of the relative goodness of fit of a statistics model, is used to find an optimized model.

Background

Bicycle accident analysis

The major reason of bicycle collisions with vehicles is loss of control because the bicycle is a single-track transportation mode similar to motorcycles. The loss of control is defined as difficulty in braking,

riding too large a bike, riding too fast, riding double, stunting, striking a rut, bump, or obstacle and riding on slippery surfaces (Consumer Product Safety Commission, 2007). In here, the slippery surface implies that the model should consider the road friction to reconstruct bicycle accident in the model. Secondly, the lightning problem causes bicycle accidents. Although about 17% of all bicycle accidents occurred in the darkness, the fatal rate in night is even higher than that of day [6]. Also 90% of accidents in night time are related to rear collision. This result is higher than day time result, 40% [7].

The statistics, accidents with passenger cars are over 77% of whole bicycle-vehicle accidents. 18% with trucks and 3% with motor cycles are shown. On the other hand, bicycle accidents with buses are just 0.4% of total accidents [6] and it shows that bicycle accidents with buses are very rare. However, the accidents have higher probability to make fatal because head injury probability is high due to the shape of buses. That is, when bus crashes with bicycle, the rider head will hit direct with bus front side, so that fatal probability is higher than other types of vehicle [3]. There is also a bicycle accident analysis based on data from national survey and the research concludes that bicycle accident risk has strong relationships with rider's age, riding distance, riding surface, bicycle type, and geographic characteristics [8].

Many previous studies have been concerned with accident fatalities with helmet usage. The analysis is based on the hospital and survey data [9]. Since most fatalities are related to head injuries, the importance of helmet usage is significant. In the United States, 48% of children always use helmet, 23% sometimes use it and 29% never use it, it means that over 50% of children are in danger when they ride bicycle. The use rate is associated with race, age and ethnicity, but no relationship with sex of child [10]. Another research reveals in the paper about relationship between helmet use pattern and household demographics that the riders who are college graduates are about three times more wear helmets than people who graduated only high school [11].

Bicycle accident reconstruction model

A study has shown simulation results of accident reconstruction in car to electric bicycle side impact crashes. The result shows that cyclists throw distance is less influenced by the road friction coefficient and vehicle load, and the distance might be larger under lower impact speeds and smaller deceleration conditions [12].

A developed model by neural networks to reconstruct the accidents with the finite element method (FEM), which has been widely used as simulation tools for crashworthiness analysis and structural optimization design needs lots of crash simulation cycles and costs [2]. Even though the simulation technologies are being used for accident reconstruction, it is necessary to develop the basic model to estimate and calculate throw distance in field study or simulation tools. Not only bicycle accident reconstruction model, but pedestrian accident reconstruction model has been studied [13].

Several previous studies have revealed the bicycle throw distance under various factors by using Mathematical Dynamic Models (MADYMO^{TM}), which is the software for analyzing and optimizing occupant safety design in the automotive and transport industries. As the vehicle impact speed increases, bicycle throw distance is farther. It means that fatalities rate will be increased when the bicycle throws far from the vehicles. In addition, head injuries rate can be determined by the point of impact and angle of approach and some studies plot the simulation pictures of head crash spots.

As there is no study presently available which determines engine hood types' impact to bicycle throws distances, this study examines this. It is clear that the impact area is different between RV, compact sedan, and bus. In here, we could not conclude that the farther throw distance causes fatality, for instance, although the throw distance when the buses hit the bicycle is less than, the fatal rate is much higher [3].

Methodology

It would be better to consider all possible factors which may be related to bicycle throw distance and vehicle stop distance, and then select the optimized model with appropriated factors. This study uses real accident data in United States, which includes vehicle manufactures, model, impact speed, bicycle throw distance, and rider throw distance. Authors investigate information of vehicles in the data such as vehicle gross weight and engine hood type. Original raw data and data that are filled by authors are shown in the Table 1. The vehicles are categorized into three, compact sedan, RV, and bus. The coefficients of friction range from 0.3, which is close to wet road condition, to 0.75, which is dry road condition. Due to lack of data for bicycle accidents with buses, we exclude this for the model development.

This paper assumes,

1. Bicycle throw distance is influenced by not only vehicle impact speed, but also other factors including vehicle gross weight, road friction, and others.
2. Bicycle throw distance may vary under different types of engine hoods.

	Manufacturer	Model	Rider throw distance (ft)	Vehicle impact speed (mph)	Bike throw distance (ft)	Impact speed	Friction	Gross weight (lb)	Engine hood type
1	Toyota	Corolla	53	21	82.5	21	0.178	2880	compact
2	Dodge	Dakota pickup	53	19.75	41.75	19.75	0.311	3051	RV

Table 1: Description of data.

This paper builds regression models based on the assumptions that mentioned above. Previous bicycle accident reconstruction models utilize regression models which have only impact speed. Impact speed must be the most critical variable to affect bicycle throw distance. However, there must be other important factors that should not be ignored and this study utilizes all kinds of data shown in the Table 1. It is very important to have methodology to find the best model among the many possible regression models.

The basic approach to find the best fitted model is using AIC value in regression models. AIC is a measure of the relative quality of a statistical method for a given set of data. This means that AIC

estimates the quality of each model and provides a means for model selection. AIC is based on Information Theory and offers a relative estimate of the information lose when a given model is used to represent the process that produces data. It deals with the trade-off between the goodness of fit and the complexity of the models. AIC does not provide a test of a model in the sense of testing a null hypothesis. The smaller AIC value shows the most fitted regression model. The AIC model can be described as below.

$$AIC = n * log(2*\pi) + n * log(SSE / n) + n + 2 * (k+1) \quad (1)$$

n: sample size

SSE: sum of squared errors

k: number of estimated parameters (including the variance)

Results

Total four models are evaluated by AIC and R squared values. The two models which have road friction or vehicle gross weight each were excluded because those are not significant at all with bicycle throw distance themselves.

Model 1 *Bicycle throw distance=β0+β1*vehicle impact speed (2)*

Model 2 *Bicycle throw distance=β0+β1*vehicle impact speed +β2*friction (3)*

Model 3 *Bicycle throw distance=β0+β1*vehicle impact speed +β2*vehicle weight (4)*

Model 4 *Bicycle throw distance=β0+β1*vehicle impact speed +β2*friction+β3*vehicle weight (5)*

Table 2 gives a summary of statistical results. Even though R squared in model 4 is the highest, the AIC value is higher than that of model 2. This implies that model 4 has a strong linear relationship between X and Y variables and model 2 fits the data in an absolute sense.

Unlike our assumption, the model with vehicle gross weight is not the best prediction model. We can estimate that the weight gaps between vehicles and bicycles are too small to apply Momentum Theory in Physics.

	Model 1	Model 2	Model 3	Model 4
n	104	104	104	104
k	1	2	2	3
SSE	28276.383	5489.310	28275.887	5479.343
R2	0.586917	0.919808	0.586924	0.919954
AIC	882.0999	713.6206	884.0981	715.4316

Table 2: Statistical result for models.

The final model based on the lowest AIC value is,

*Bicycle throw distance (feet)=4.69+3.68*Vehicle impact speed (MPH)−101.12*Friction (6)*

The positive coefficient for vehicle impact speed implies that bicycle throw distance increases with vehicle impact speed growth and the negative coefficient for the road friction means the drier road frictions make the shorter bicycle throw distances. For each increase in 10 mph vehicle impact speed, the estimated average vehicle throw distance increases 36.8 feet.

Figure 2 shows the 3D plot for the model (6).

Figure 2 illustrates bicycle throw distances under different vehicle impact speeds and road frictions coefficients. It is clear that lower friction coefficient makes longer bicycle throw distance at the same speed because the friction coefficient is the meaning of wet road condition. On the other hand, bicycle throw distance is shorter at high friction coefficient which means dry road condition.

Distinguished two models for different engine hood types were developed. The engine hood types can be described as the heights of engine hood or shapes of vehicle front side. As shown in Figure 4, RV and compact sedan have different impact areas against bicycle. RV may hit the whole bicycle body, on the other hand, compact sedan hits bicycle wheel height. A research concludes that different first contact position of bicycles with vehicles affect bicyclists head strikes [14].

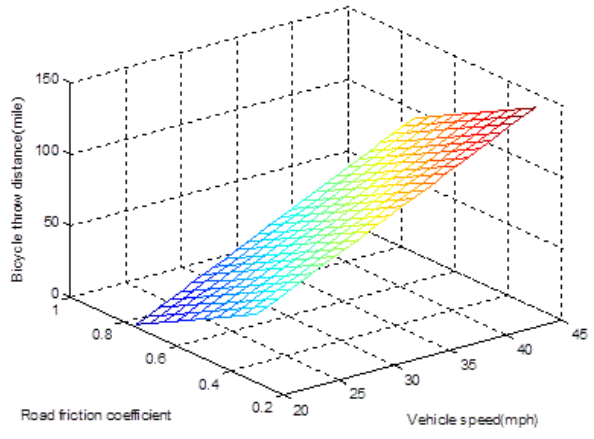

Figure 2: 3D plot for final model.

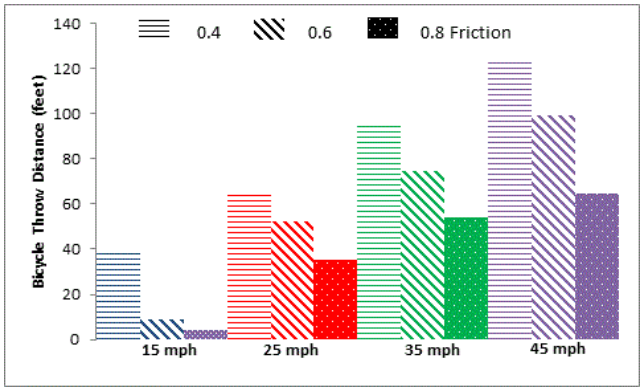

Figure 3: Bicycle throw distance with different vehicle impact speeds and road frictions.

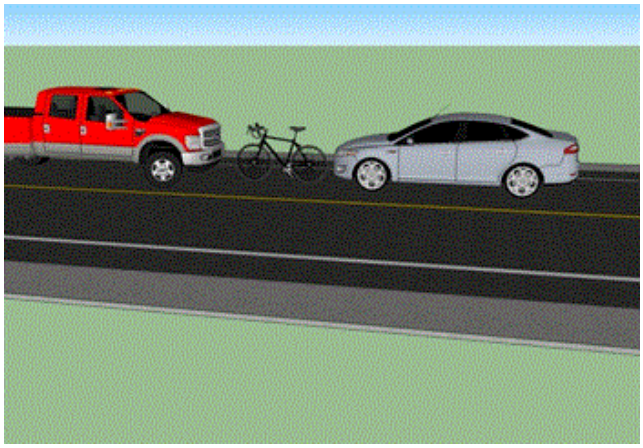

Figure 4: Different impact areas for RV and compact sedan.

The bicycle reconstruction models for compact sedan and RV are shown below, respectively.

Compact sedan

*Bicycle throw distance (feet)=6.66+3.62*Vehicle impact speed (MPH)−101.16*Friction* (7)

RV

*Bicycle throw distance (feet)=-9.78+4.04*Vehicle impact speed (MPH)−95.69*Friction* (8)

This study evaluates the accuracy to reconstruct accidents of the developed and suggested model by comparing with the model that previous research developed with only vehicle impact speed as shown in equation (9).

*Bicycle throw distance (feet)=-19.88 + 2.71*Vehicle impact speed* (9)

The bicycle throw distance is estimated 88.52 feet under 40 mph vehicle impact speed by the above model, but the bicycle throw distance ranges from 76.05 feet (16.40% smaller) to 121.55 feet (37.31% larger) according to road friction from 0.3 to 0.75. 88.52 feet can be explained under 0.63 road friction, which means the dry road condition. That is, the equation (6) with only vehicle impact speed variable could not predict the bicycle throw distance in accuracy.

To evaluate the model suggested, this study tests the model with real accident data. The estimated bicycle throw distance is 56.22 ft by using the data, the impact speed and vehicle type are 27.5mph and Toyota Corolla (this paper investigates all specifications including gross weight and engine hood type for this model), respectively. The gap between the estimated (56.22 ft) and real value (52.5 ft) is acceptable. This would not be possible without the consideration of various factors that are not considered in other studies.

Conclusions

First of all, this paper contributes to the building of bicycle throw distance estimation model; it can be applied to investigate accidents and contributes accident reconstruction. As we discussed above, the developed model with vehicle impact speed and road friction in this paper shows improved accuracy to predict bicycle throw distance. The key finding here is that it is possible to estimate vehicle impact speed with bicycle throw distance and road friction in accidents. In addition, the vehicle gross weight is not a significant factor to estimate the throw distance because the gaps between vehicle gross weight and bicycle weight is too small to apply Momentum Theory in Physics.

It would be obvious that there are differences between RV and compact sedan, that is, the bicycle throw distance varies according to the vehicle types, RV or compact sedan. The previous model which does not consider engine hood types and road friction lowers accuracy for estimation and the model suggested in this research must be a solution to cover the weaknesses of the previous model.

Although there has been a great deal of bicycle accident reconstruction model, there is little research estimating bicycle throw distance according to the various factors that suggested in this paper. The model from this study can guide bicycle throw distance estimation model adoption and it can help bicycle accident reconstruction model have more accuracy.

Our study has its limitation, which may be addressed by future research. First, it would be interesting to see the angle of impact and each vehicle's weight, not gross weight in the specifications such as number of passengers. Secondly, demographics of drivers including driving experience, age, gender, and others need to be analyzed because the stop distance can be determined by those as well.

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