Motorcycle Accident-Prone Types at Intersections and Innovative Improvement Design Guideline

Hsu, Tien-Pen a, Ku-Lin Wen b

a,b Department of Civil Engineering, National Taiwan University, Taipei, 106, Taiwan
a E-mail: hsutp@ntu.edu.tw
b E-mail: wengulin@ntu.edu.tw

Abstract: In the past, traffic engineering designs are mostly based on car traffic volume, delay, and travel time and efficiency oriented. However, the traffic composition and traffic volume of motorcycle are very high in Taiwan and in some Asia countries as well. The traffic engineering design must take motorcycles into consideration. Besides, proportion of motorcycle in the accident casualty is also very high, and furthermore, the number of motorcycle causality is increasing in recent year. In the past, the segregated flow concept to substitute for mixed traffic has been implemented and has caused the decrease of the death accident. However, the injured accidents is still increasing continuously. Therefore, the study aims at analyzing the accident data using collision diagram and an accident diagnosis process to find out the traffic engineering design problem and to propose the new design method for reducing motorcycle involved accidents.

Keywords: Accident, Motorcycle, Traffic Safety, Collision Diagram, Traffic Flow Dynamic

1. INTRODUCTION

The Decade of Action for Road Safety 2011–2020 was proclaimed by the United Nations General Assembly in 2010 (United Nations 2010). Every country tries to improve road safety by different polices. However, Taiwan’s traffic safety environment become worsening in recent years. From last ten year (2003~2013) statistics shows that the growing rate of registration number of car and motorcycle is 1.95% and 1.55% respectively. However, the growth rate of accidents of car and motorcycle is 4.26% and 12.64% respectively. The number of motorcycle accidents increase more significantly. Accident data shows that in the collision between motorcycle and car the main injured group is motorcycle rider. Therefore, the research focuses on improvement of motorcycle safety, in order to prevent collision between motorcycle and other road users. Figure 1 shows the vehicle number and accident data in recent years.
Resulting from the analysis of accident data of recent three years, the motorcycle accident sites are mostly located at intersection or near intersection, about 49%, as shown in Figure 2. In Taiwan, now a day, motorcycle traffic safety facilities basically contained two-stage left turn waiting zone, motorcycle waiting zone, permissive motorcycle lane, and exclusive motorcycle lane etc. in the past. Although these design methods could separate motorcycle from the other car traffic flow and could be expected to reduce the accident between the motorcycle and car. The deaths number of accidents is reduced. However, the motorcycle injury number is still increasing. It implicates some accident problems are unclear. The study would apply traffic flow dynamic analysis and collision diagram method to investigate these problems. Then, a new motorcycle safety design guideline was proposed accordingly.
2. LITERATURE REVIEW

In order to conduct analyzing accidents at intersection and proposing design methods, the study would briefly review the researches of motorcycle traffic facility in operation, motorcycle traffic characteristics in the past. In some Asian countries, such as Vietnam, Thailand etc. they also have large number of motorcycles. Their major accident fatality group is still the motorcyclist, similar with the situation in Taiwan (Hsu 2004, Ponboon etc. 2010, Nguye 2014). However, in these countries they have not the same countermeasures like segregate flow at intersections in Taiwan, even the traffic problems raised by motorcycle are similar in every country (APEC Transportation Working Group 2010, Hsu 2004).

2.1 Segregated Flow Design for Motorcycle

The segregated flow design countermeasures implemented in Taiwan consists of motorcycle exclusive lane, motorcycle waiting zone, two-stage left turn of motorcycle etc. (Hsu 1998). Because motorcycle is the main travel mode in Taiwan, overall traffic system should provide reasonable space and suitable traffic facilities exclusive for motorcycle. The main motorcycle traffic improvement principles in Taiwan in the past include:

1. Installing traffic island or marking to separate motorcycle from other motorized vehicles.
2. Providing head start waiting zone for motorcycle to depart before the car at intersection.
3. Two stage left-turn regulation for motorcycle.
4. Traffic regulation facility should be designed for vehicle and motorcycle differently.

2.2 Motorcycle Traffic Characteristics

The motorcycle traffic characteristics could be concluded generally as follows:

1. Waiting and departure characteristic at intersection

   In Taiwan, motorcycle rides on the right side of the road. Most motorcycles move forward to the stop line as close as possible and then to wait during red time at motorcycle waiting zone at intersection. Motorcycles would stop over the stop line due to the layout of two-stage left-turn waiting zone (Hsu, et al. 1994). Comparing the difference of departure characteristics under with and without head start waiting zone for motorcycle, the results depict that the total delay at intersection would decrease and the departure rate would increase under provision of two stage motorcycle waiting zone and head start waiting zone for motorcycle (Hsu, et al. 1998).

2. Motorcycle’s passenger car equivalent and traffic capacity characteristics

   Generally speaking, the motorcycle’s passenger car equivalent (PCE) is 0.3 in Taiwan Highway Capacity Manual (Institute of Transportation 2010). However, the motorcycle’s PCE would decrease when the motorcycle’s mixture composition increases (Hsu 1996, Institute of Transportation 2010).

2.3 Motorcycle Traffic Safety

The main reason for the rapid increasing number of motorcycle accidents is not only the increasing number of motorcycle ownership and/or motorcyclist behavior, but also the lack of effective motorcycle traffic facility for enhancing motorcycle traffic safety. Besides, motorcycle
accidents often are caused by the influence of local street environment, the characteristic of intersection layout and traffic movement characteristics of various vehicles. Therefore, how to find out the better traffic engineering design countermeasures is one of the most important issues for the countries with high motorcycle traffic volume.

3. ACCIDENT-PRONE INTERSECTION ANALYSIS

The study selected several accident-prone intersections to draw the accident collision diagrams in order to identify the main accident types at intersections. After that, traffic flow dynamic analysis method is used to analyze traffic conflicts related to the accident types. From the result of traffic flow dynamic analysis and accident diagnosis based on collision diagram, the causes of accidents are identified. Based on it, various safety improvement countermeasures are proposed. Finally, the study developed a new motorcycle safety design guideline. The flow chart of the study is shown in Figure 3.

![Flow chart of the study](image)

Figure 3. Research flow chart to develop new motorcycle safety design guide

3.1 Accident Investigation Method

By using the accident diagnosis analysis based on collision diagram, the relationship between accident and geometry design and traffic engineering countermeasures at intersection could be identified. The process for generating collision diagram contains drawing geometric layout
condition diagram of intersection and accident collision diagram. The intersection condition diagram shows the geometry design, control facility, road type, signal timing, signal head location etc. Accident collision diagram illustrates different collision types at different locations at intersection. Besides, it also shows the accident consequence, road situation, light situation...etc. By using special symbol combination could mark each accident at the intersection clearly. The collision legends are shown in appendix.

3.2 Traffic Flow Dynamic Analysis
The research applied video recording method to get field traffic flow data, and then using digitalized image method to count the traffic flow dynamic trace at intersection. After that, the research could get the motorcycle and car traffic flow variation of position, velocity, and acceleration, especially with respect to the conflict situation. The process using image processing and digitalized method to get the data is shown in Figure 4.

3.3 Method for Creating Improvement Street Design Countermeasures
The safety enhancement design countermeasures are generated from accident diagnosis of the collision diagram at intersections. From collision diagram, the main motorcycle collision types would be identified. Then, the study has discussed the causes of each main collision type, including the factors of environment, geometry design, traffic control, and traffic characteristic etc.

4. MAJOR SAFETY PROBLEMS AT ACCIDENT-PRONE INTERSECTIONS
From accident statistics’ analysis using the data bank of national accident data(Institute of Transportation 2013), the major collision types between car and motorcycle are turning movement other angle collision (40.4%), same direction’s sideswipe collision (14.2%), right-angle collision (13.4%), rear-end collision (10.7%) etc. It shows that existing motorcycle facility at intersection can’t solve the problem of the increase of accident number involved by motorcycle. Therefore, the study would find out the conflict problems at intersection by traffic flow dynamic analysis.

4.1 Left Turn Conflict Analysis
Taking the intersection of Zhong-zheng Rd. /New Taipei Rd. in New Taipei City as case (Institute of Transportation 2014), the southwest bound of the intersection occurred a lot of left-turn other angle collisions of motorcycle crashed against the straight car at same direction. Resulting from field traffic survey, there are 20.8% of motorcyclists make the direct left turn illegally, but not follow the two stage left turn regulation rule at the intersection. Therefore, the collisions between illegal left-turn motorcycles and other straight vehicles occurred frequently,
as shown in Figure 5. It illustrates a typical problem of motorcycle left turn regulation.

![Figure 5. Example of collision diagram of Intersection of Zhongzheng Rd. /New Taipei Rd.](image)

Furthermore, in some other small intersections, there is usually not two-stage left turn regulation for motorcycle. Left turn motorcycle is allowed to make left turn directly. However, under this situation, some motorcycles are used to ride on the curb side lane to make left turn. It will cause the conflict with the straight traffic. Because current guideline doesn’t provide the design method for motorcycle direct left turn at such type of intersection, the research would investigate and propose new countermeasures to make motorcycle direct left-turn safer.

### 4.2 Conflict of Right Turning Traffic and Straight Traffic

Taking Intersection of Zhongzheng N. Rd. / Chongyang Rd. as case (Institute of Transportation 2014), the collision diagram and the stop line coordinate A and B are shown in Figure 6. From the collision diagram, it shows that the accident risk between straight traffic flow and right turning traffic flow at south and west bound is very significantly high at the intersection, because the right turning vehicle will not keep right and the straight motorcycle will ride on the right side of the lane.
A field observation of dynamics traffic flow is conducted at the intersection. Taking location “A” in Fig.6 as example, the survey results show that 6% of right-turn vehicle still don’t keep on right side lane at intersection. Besides, 57.6% of straight motorcycle also rides on the right side of lane. Collision risk exists between these two traffic movements. Taking location “B” in Fig. 6 as example, the results show that about 3.7% of right-turn vehicle still don’t keep on right side lane at intersection. Besides, 89.1% of straight motorcycle also rides on the right side lane. Collision risk exists between these two traffic movements. The survey result of traffic flow are shown in Figure 7.

Figure 6. Collision diagram and intersection coordinate of Zhongzheng N. Rd./ Chongyang Rd.

![Collision diagram and intersection coordinate of Zhongzheng N. Rd./ Chongyang Rd.](image)

Figure 7. Right-Turn traffic flow conflict analysis

From analysis above, it shows that right-turn traffic movement isn’t directed to right side lane at intersection and then cause the conflict against straight motorcycle traffic movement. Therefore, signs, markings, and control measures need to be improved to guide different
direction traffic flow to different lane location separately.

4.3 Inter-green Time and Traffic Flow Conflict Analysis

Taking the intersection of Chongsheng Rd. / Hanson E. Rd. as case (Institute of Transportation 2014), the accident risk exists between south bound stopping traffic flow after end of green time and east bound starting traffic flow at the beginning of green time, as shown in Figure 8. Therefore, the research suggests increasing red time and yellow time to improve right-angle collision according to the layout of intersection for motorcycle.

![Figure 8. Collision diagram of intersection Chongsheng Rd. / Hanson E. Rd. and stopping and starting traffic flow bound](image)

After the setup of a new longer inter-green time at this intersection, by conducting a field observation of traffic flow using video afterwards, the study analyzed the traffic flow crossing stop line on green time ending bound and green time starting bound. The analysis result shows that crossing stop line vehicles afterwards decrease from 40.4% to 17.0% due to the longer all-red time on green starting bound afterwards, and the vehicles passing the stop line after ending of green time are reduced, as shown in Fig. 9. The risk of right-angle collision will decrease significantly.
Figure 9. Before and after analysis of traffic conflict analysis by different inter-green time

The analysis results above show that inter-green time rule in the national guide of traffic signal at intersections needs to be revised accordingly in order to ensure motorcycle crossing intersection safely.

5. MOTORCYCLE FREQUENT COLLISION TYPE ANALYSIS

Resulting from the analysis of major Safety problem at intersections, we found out that there are some most frequently occurred collision type involved by motorcycle at intersections, which are right-turn other angle collision, same direction sideswiped collision, left-turn other angle collision, opposite left-turn other angle collision, rear end collision and right angle collision etc. The research would discuss accident issues and safety improvement design for motorcycle accident-prone intersections regarding these collision types.

5.1 Right-Turn Other Angle Collision, Same Direction

At intersection with exclusive motorcycle lane, permissive motorcycle lane, or with express/slow lane traffic divider, right-turn vehicle often don’t move to right side lane to make right turn. The right-turn other angle collision between right-turn vehicle and straight motorcycle often occurred at such lane layout. A typical case is shown in Figure 10 (Hsu, 2013). At south bound of the intersection, exclusive motorcycle lane is installed. Because the width is not enough to set up an extra lane, the research cancels exclusive motorcycle lane 50m upstream of the stop line at intersection and make the curb lane as mixed lane for car and motorcycle. Then, right-turn vehicle can change to curb side lane before arriving intersection and them make right. The conflict between straight motorcycle and right-turn vehicle could be prevented, as shown Figure 10.
5.2 Sideswiped Collision, Same Direction

Because traffic movements at different direction will use the same lane under mixed traffic with motorcycle, the right-turn car and straight motorcycles will weave to cross to each other within a lane. Therefore, sideswiped collision occurred frequently on such a lane at intersection. A case is shown is Figure 11 (Hsu, 2013). The width of mixed lane is sometimes too wide. Then, the right turn vehicle will not make right turn on the right side of lane, and it will cause conflict with the straight traffic on its right side. In such case, it needs facility to guide straight vehicle to use the left side of the lane and right-turn vehicle to use right side of lane. It needs to guide different traffic movements by setting diverging markings for keeping motorcycle away from conflict. Besides, the new direction markings are also proposed at the motorcycle waiting zone to remind motorcyclists to use the collect locations to segregate the different direction movements. The improvement design is shown in Figure 11.
5.3 Left-Turn Other Angle Collision, Same Direction

Left-turn other angle collision between direct left-turn motorcycle and straight vehicle or motorcycle often occurred at intersection with the lane layout of slow traffic lane or mixed lane. An example of intersection is shown in Figure 12. Resulting from field traffic survey at this intersection, many motorcycles make left turn from west bound to north bound don’t follow two-stage left-turn regulation for motorcycle. Considering motorcycle traffic characteristics and geometry at intersection, the new design is proposed by removing the slow traffic lane or mixed lane for motorcycle, and then to install motorcycle direct left-turn guiding marking instead. It would separate different directions of car and motorcycle traffic movements, and then, the traffic conflicts will decrease. The improvement design is shown in Figure 12.
At the intersection lacking left-turn protected signal phase, left-turn vehicles often finish left turn after ending of green time. Sometimes, at this moment, the motorcycles on opposite lane are still on departing the intersection. The collision between left-turn vehicle and opposite straight motorcycle often occurs under such situation. An example of intersection is shown in Figure 13. It can be improved by reducing central-divided-island, adding left-turn signal phase, or installing left-turn guiding line etc. Then, the conflicts between left-turn vehicle and opposite motorcycle could be prevented. An example of improvement design is shown in Figure 13.

Figure 13. Collision and improvement design of intersection of Nanjing Rd. / Cathay Rd. in Kaohsiung city

5.5 Rear End Collision and Right Angle Collision

When motorcycle approaching intersection, some motorcycles or vehicles are deciding to stop, but some vehicles in front cannot stop during inter-green time, the rear-end collision will occur. A case of collision at intersection is shown in Figure 14. Although the yellow time is set up to theory of yellow time, but at such intersection, a longer yellow time is needed to reduce the rear-end collision. On the other hand, if it lacks of enough all-red time, motorcycle couldn’t leave intersection before all-red time ends, and right-angle collision will occur, as shown in Figure 14. Although the all-red time is set up to theory of all-red time, a longer all-red time is needed to prevent the right-angle collision. Therefore, the inter-green time is needed to modified for preventing the left-turn other angle collision.
6. NEW DESIGN GUIDELINE FOR ENHANCING MOTORCYCLE TRAFFIC SAFETY

Through a series of analysis of traffic flow dynamic, collision diagram, and traffic survey, the study proposes some innovative design concepts for enhancing motorcycle traffic safety. The new design concepts are also proved to be able to benefit the improvement of motorcycle traffic safety at intersection by conducting before-after traffic flow dynamic analysis and the questionnaire survey to drivers and motorcyclists. The study integrates innovative design methods and collision statues to establish new motorcycle safety design guideline at intersection.

6.1 Design for Motorcycle Direct Left-Turn

Currently, at the intersection on one-lane and tow-lane road it usually hasn’t two stage left-turn regulation measures for motorcycle. Besides, at the intersection with two-stage left-turn regulation for motorcycle, sometimes, motorcycle would violate the two-stage left-turn rule and make direct turn left with vehicle together at some intersections where it has two stage left-turn control measures. Both situations would cause left-turn collision. Therefore, the research considers signal timing, lane layout, and accident data…etc. Instead of two-stage left-turn regulation for motorcycle, under some conditions as follows, the intersections will be suitable to allow the motorcycle to make direct left-turn:

1. At the intersection with left-turn protection phase, direct left-turn should be considered if there is no express traffic lane (only for car)/slow traffic lane(allowed for motorcycle) divider.

2. At the intersection with no left-turn protection phase, if there is no express/slow traffic flow divider and the number of lane is one or two lanes, then motorcycle direct left-turn should be considered. If there is express/ slow traffic divider and the number of accident for direct-left turn motorcycle amount is 3 times or more, direct left-turn also should be
considered.
3. If the intersections don’t comply with the above, two-stage left-turn should be considered.

For the design of motorcycle direct left-turn, some new marking and signs should be created, such as diverging markings, diverging sign, and lane-waiting zone.

6.2 Diverging Traffic Movement

6.2.1 Diverging traffic movement marking

In order to guide turning vehicles and motorcycles to use proper space for turning at intersection, the study proposes a diverging traffic movement marking to prevent turn collision and sideswipe collision. This method especially could be applied at wide mixed lane. The marking design principle and symbol are shown in Figure 15.

1. The location of merging marking should be sited at least 80m upstream of the stop line, 100m is suggested.
2. The location of diverging marking (I) should be sited at least 30m upstream of the stop line, 50m is suggested.
3. The location of diverging marking (II) should be sited before motorcycle waiting zone.
6.1.2 Diverging traffic flow sign

In order to strengthen the diverge of traffic flow of different directions, the study suggests that a new sign for guiding turning movement are sited 100m upstream of the stop line, as illustrated in Figure 16.
Figure 16. Diverging sign for direct left turn and right turn movement

6.3 Uninstall Slow Traffic Lane, Changed to be Mixed Lane

At the intersection with exclusive motorcycle lane or permissive motorcycle lane, the conflict between motorcycle on motorcycle lane and other motorized vehicles on mixed traffic lane would occur frequently. For improving this situation, motorcycle lane or slow traffic lane should be removed on at least 60m upstream of intersection and to install a mixed lane for motorized vehicles instead. It will reduce the traffic conflicts between different driving direction vehicles, as shown in Figure 17.

Figure 17. The improvement method to remove slow lane or motorcycle lane

6.3 Lane-Waiting Zone for Motorcycle

The concept of lane-waiting zone is an improvement of conventional waiting zone. It is to draw motorcycle waiting zone for each lane, and in the waiting zone to draw direction arrow. It is to separate different vehicles such as car and motorcycle, but also diverge different directions of traffic flow such as straight, left-turn, and right-turn movement effectively. Under such layout, motorcycle and other motor vehicles can move to proper location by guiding sign and diverging traffic markings on mixed traffic lane. Besides, motorcycle riders can move to proper location...
for turning following the marking at lane-waiting zone. It is able to decrease the probability of turning collision and sideswipe collision. Considering left-turn regulation type and lane layout, the study proposes the lane waiting zone design guideline as follows:

1. At the intersection, with various directions of motorcycle stopping in a motorcycle waiting zone, both the turn marking and straight markings should be drawn within motorcycle waiting zone.
2. At the intersection, on the lane without left-turn motorcycle, the straight marking should be installed in motorcycle waiting zone if the number of lane is 3 or more.
3. At the intersection with motorcycle direct left-turn and the number of lanes is 2 or less, in such case, usually, one lane for left-turn and straight traffic; another lane for right-turn and straight traffic. The left-turn marking should be drawn at the left corner of waiting zone at left side lane and the right-turn marking should be drawn at the right corner of waiting zone on the right side lane for diverging the motorcycle movements.

Combining with the lane-waiting zone, the lane marking will be designed by taking lane layout, lane width, and flow direction of lane into consideration. Its design guidelines are proposed as follows:

1. If the slow traffic lane or motorcycle exclusive lane exists, the slow traffic lane should be removed from at least 50m upstream of the stop line and changed to be mixed lane for motorized vehicles. Besides, diverging markings are applied to guide the traffic flow.
2. An arrow markings would be used to guide motorcycle forward to motorcycle lane-waiting zone, as shown Figure 18.
3. Motorcycle lane-waiting zone symbol, arrow markings at motorcycle waiting zone, and diverging marking on lane should be considered with design together respectively.
6.4 Inter-green Time Improvement Design

The inter-green time is highly related to rear end collision and right angle collision at intersections under consideration of motorcycle driving behaviors. Different road types need different design methods, as follows:

1. Intersection on the road without express traffic lane (car only)/slow traffic lane (mixed traffic with motorcycle) divider

   According to the definition of Inter-Green time, it consists of yellow time and all-red time. On the street without divider between the express traffic lane for car only and slow traffic lane for mixed traffic with motorcycles, called central divided street, a movement crossing an intersection will pass through car movement, which is mostly in the middle of street and motorcycle movement on the right hand side. The all-rad time should be long enough for the car and/or motorcycle to pass through these two movement. The time needs to take the acceleration characteristic and speed limit both of car and motorcycle into consideration.

2. Intersection on the street with express/slow traffic divider

   On the street with divider between express traffic for car only and slow traffic for mixed traffic with motorcycle, called express/slow divided road in Taiwan, speed limit of express lane is usually 60kph, and the speed limit of slow traffic lane is usually 40kph. Therefore, the study suggested that inter-green time should apply express lane speed limit 60kph for calculating the yellow time and the slow traffic lane speed limit 40kph for the all-red time to provide safer design.

7. CONCLUSION AND RECOMMENDATION

This paper investigated the collision status of mixed traffic flow with high motorcycle traffic volume, and found out the accident causes by accident diagnosis based on collision diagram analysis. Finally, the study proposed traffic safety engineering improvement countermeasures for enhancing the safety of motorcycle traffic. Through a series of the innovative design countermeasures for concept of motorcycle direct left-turn design and lane-waiting zone design, the motorcycle traffic safety could be enhanced. The study proposed that the motorcycle safety design guideline. It can be taken as the practical design basis for road design for enhancing motorcycle traffic safety.
APPENDIX

Result of accident

- A3 accident
- A2 accident (no. of injured)
- A1 accident (no. of death)
- Accident with injured and death

Party of accident

- Vehicle
- Heavy vehicle
- Motorcycle (age)
- Bicycle (age)
- Pedestrian (age)

Road condition

- Dry road
- Moist road

Light condition

- Daytime
- Night

Driver’s status

- Back
- Brakes
- Speeding
- Out of control
- Stop vehicle
- Temporarily stop vehicle
- Under control stop vehicle
- Rotate
- Violating driving

Special Data

- Alcohol (mg/l)
- Signal out of operation
- Stop and give way
- Not stop or not give way
- Barrier on road or roadside

Figure 19. Collision diagram basic symbol

Head on accident

- Head on
- Head on, left-turning

Rear end accident

- Rear end
- Rear end, backing vehicle
- Rear end, left-turn vehicle
- Rear end, stopped vehicle

Right angle accident

- Right side right angle
- Left side right angle

Sideswiped accident

- Opposite sideswiped
- Right-turn sideswiped

Turn accident

- Right-turn merging vehicle
- Left-turn merging vehicle
- Right-turn other angle, same direction
- Left-turn other angle, same direction
- Left-turn other angle, opposite direction

Out of control accident

- Out of control

Figure 20. Collision type symbol
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2145