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Influencing Factors on Conflicts of Turning Vehicles and Pedestrians at Intersections

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Disclaimer

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Influencing Factors on Conflicts of Turning Vehicles and Pedestrians at Intersections

SHRP 2 Implementation Assistance Program (IAP) – Round 4, Phase 1 Report

Center for Advanced Transportation Education and Research (CATER)

Hao Xu
Chuck Reider
Zong Tian
Hualiang Teng

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1. INTRODUCTION

The FHWA reported that in 2013, there were 4,735 pedestrians killed and an estimated 66,000 injured in traffic crashes in the United States in which a large proportion occurred at intersections [(1)]. Pedestrian safety and intersection safety are critical areas of emphasis in the Nevada Strategic Highway Safety Plan (SHSP) [(2)]. Awareness of safety issues at intersections is one of the major strategies. The movement of pedestrians often conflicts with turning vehicles at intersections caused by either shared signal phases at signalized intersections or competitive right of way at unsignalized intersections as shown in Figure 1. Crashes between pedestrians and turning vehicles are named as pedestrian-turning-vehicle crash in this report. Pedestrian-turning-vehicle crashes count a major part of intersection pedestrian crashes, especially taking into consideration that the turning traffic volumes are normally lower than through traffic volumes. For example, Nevada crash data of 2006-2012 shows that a third of pedestrian crashes at intersections involved turning traffic and half of the intersection pedestrian crashes in Washington State involved turning vehicles based on the data of 2006-2013. In order to decrease the pedestrian-turning-vehicle crashes and improve pedestrian safety at intersections, it is important to understand the influence of various factors on turning-drivers' behavior.

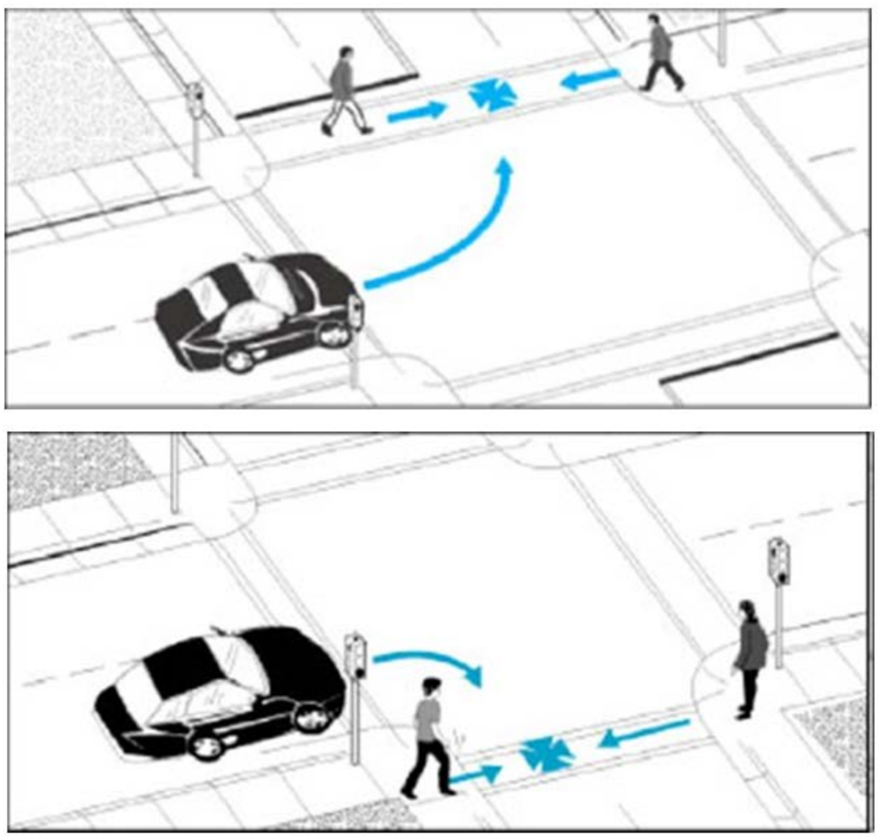

Figure 1. Pedestrians conflicting with left and right turning vehicles [(3)]

While pedestrian crashes are critical, they are low probability events. Crash data is very limited compared to the non-pedestrian crashes, even though a large number of studies on intersection pedestrian safety have been conducted. The traditional data with limited amount and details were used to study statistical relationship between crashes and contributing factors, but not why and how such factors impact the performance of safety. Thus, new data elements and data sources need to be considered for a comprehensive understanding about the influencing factors and related countermeasures. SHRP 2 Safety Data, including the Naturalistic Driving Study (NDS) data [4] and the Road Information Database (RID) data [5], provide a continuous description of drivers, vehicles roadways and environments. The NDS data includes time-series records from the sensors installed on the volunteer vehicles and multi-directional video clips. The RID contains comprehensive roadway and environmental data related to the NDS road network. The SHRP 2 dataset is currently considered to be better than other existing transportation datasets in the U.S. when taking into consideration the information details and data size.

Vehicle drivers are expected to yield to pedestrians when there are conflicts, however drivers may fail to see pedestrians and react to pedestrians when they are influenced by various factors such as the surrounding traffic, intersection geometric, vehicle condition or driver condition. This Implementation Assistance Program (IAP) project sponsored by the second Strategic Highway Research Program (SHRP 2) is to study how driver, vehicle, roadway and environmental factors affect the turning-drivers vision and yielding to pedestrians at intersections with the RID and NDS data. Research findings will be used to guide development and implementation of effective countermeasures for pedestrian safety at intersections. The Phase 1 project was a proof of concept using reduced SHRP2 safety data. In this phase, the research objective was to demonstrate the ability to conduct meaningful research in advancing our understanding of driver behavior using the new SHRP2 safety data. This report documents the results of the Phase 1 research performed by the Center for Advanced Transportation Education and Research (CATER) at the University of Nevada, Reno (UNR) and supported by the Nevada Department of Transportation (NDOT). With the full RID dataset and the NDS data at selected intersections, the influence of different factors on driver observation behavior was analyzed, and quantified as a factor influence index. Selected factors were prioritized based on the developed factor influence index matrix. The relationship between pedestrian-turning-vehicle crashes and driver behavior pattern, and the relationship between countermeasures and driver behavior were also studied with two cases for research method demonstration. Conclusions on the Phase 1 project and recommendations for future research were provided for countermeasure selection and development with the new SHRP 2 Safety Data. In this report, the Phase 2 research proposal is included with a schedule and budget.

This report is organized as follows: Chapter 2 presents the literature review on the understanding of pedestrian crashes and recommended counter measures to avoid pedestrian-turning-vehicle crashes; Chapter 3 introduces the data used and data processing procedure; Chapter 4 documents the methodologies used in the Phase 1 study; Chapter 5 summarizes research results; Chapter 6 proposes the future research direction; and Chapter 7 is the proposal for the SHRP 2 IAP Phase 2 project.

2. LITERATURE REVIEW

Numerous studies on pedestrian safety have been conducted with different data and methodologies. The main focus has been to explore the factors associated with the severity and frequency of pedestrian crashes; and countermeasures that best address pedestrian fatalities and injuries. The impact of intersection and roadway segment characteristics on pedestrian safety was studied. [6] Several contributing factors have been identified and countermeasures were recommended based on those studies.[7,8] The countermeasures for pedestrian safety at intersections and midblock were also evaluated. Tamara Redmon (9) summarized the before-after evaluations of pedestrian countermeasures installed in Las Vegas (10), Miami, and San Francisco. Most of the evaluations were based on crash data or conflict data. In these studies, limited research was specifically related to conflicts between pedestrians and turning vehicles at intersections.

The existing research on pedestrian-turning-vehicle crashes mainly focused on the basic trend of crash frequency and rate, such as the ratio between right-turning-vehicle crashes and left-turning-vehicle crashes. (11,12,13) And another area was the traffic signal strategies' impact on pedestrian-turning-vehicle crashes, such as the protected left turn phase vs. permitted left turn phase (14, 15)) and right-turn-on-red (RTOR) (16). Major findings from the previous studies concluded that the pedestrian crash rate of left-turning vehicles is higher than the crash rate of the right-turning vehicles; protected left-turn is safer than the permitted left-turn for pedestrians; RTOR shows obvious relationship to the pedestrian-turning-traffic crash; and T intersections have a higher traffic conflict rate than X-intersections. Pedestrian-turning-vehicle frequency was also found to be related to several contributing factors, such as the pedestrian volume, traffic conditions and intersection geometric features. (15, 17)

The "AASHTO Guidance for Implementation of the AASHTO Strategic Highway Safety Plan" (18) provides a list of contributing factors and countermeasures for thirteen pedestrian crashes which include the pedestrian-turning-vehicle crashes. Another report (6) developed in 2004 also summarized countermeasures for pedestrian-turning-vehicle crashes. Some of the existing countermeasures for pedestrian-turning-vehicle crashes are summarized in the following list:

- Traffic signal
    - Advanced pedestrian traffic signal, such as early release, late release, exclusive, and scramble timing
    - Right-Turn-on-Red Restrictions
    - Protective left turn signal
- Traffic signs
    - Pedestrian and motorist warning signs, such as YIELD TO PEDESTRIANS WHEN TURNING sign, PEDESTRIANS WATCH FOR TURNING VEHICLES sign, three-section WALK WITH CARE signal head, and others
    - Advanced traffic signs, such as electronic signs indicating when pedestrians are crossing, advance yield markings reminding drivers to yield in advance of the crosswalk, and Overhead Flashing Amber Beacons
    - Dynamic lighting
- Geometric design
    - Reduced right-turn curve radius
    - Cut through at the refuge island which forces pedestrians to look in the direction of approaching vehicles before crossing the second half of the roadway
    - Diverters preventing certain through and/or turning movements at residential street intersections

The evaluation studies have shown effectiveness of the recommended countermeasures. However, it is still not clear how the different countermeasures and strategies change drivers' behavior and driving pattern. Understanding the detailed influence of the different factors and countermeasures will help select countermeasures with a better benefit/cost ratio or develop new, more effective countermeasures.

3. SHRP 2 DATA AND DATA PROCESSING

To answer the question of how driver, vehicle, roadway and environmental features affect the turning drivers' vision of conflicting pedestrians, the RID data and NDS data at selected intersections were requested. The full RID data was received. The received NDS data included time series records (sensor data records) and front videos of 600 trips collected at 6 intersections including 4 intersections in Washington and 2 intersection in Florida. Driver videos of the 600 trips were reviewed and analyzed at the VTTI data enclave.

3.1 RID Data

The SHRP 2 RID is a spatially enabled geodatabase to store, query, and manipulate geographic data of points, lines, and polygons. The roadway information was in the Geographic Information System (GIS) data format and also located by the linear referencing system (LRS). The ESRI GIS software package ArcGIS was selected to process the SHRP 2 RID data. The linear referencing system allows the geographic processing with ArcGIS Linear Reference Functions.

In the Phase 1 study, only the RID data of Washington State were processed and used because of the comprehensive crash data (2006-2013) which was provided by the state. The crash data were first selected by location, in the 300 feet radius range of the intersection nodes, in order to identify the intersection crashes. The results were further queried by the number of pedestrian involved (>0) and vehicle actions before the crash (turning left/turning right). The final query results were the crashes between pedestrians and turning vehicles which occurred at intersections. The pedestrian-turning-vehicle crashes were then joined with the RID intersection layer, the supplemental Highway Performance Monitoring System (HPMS) layer (roadway properties), the RID alignment layer (detailed curve data) and the RID location layer (grade and cross slope data). After the spatial join procedure, a new pedestrian-turning-vehicle crash dataset was generated by integrating the crash information with its related road and intersection information.

3.2 NDS Data

The received NDS data included time series records (sensor data records) and front videos of 600 trips collected at 6 intersections. There were 4 intersections in Washington and 2 intersection in Florida. The 4 intersections located in Washington were with the highest pedestrian-crash frequencies for the years 2006-2013. They were selected to analyze driver observation behavior which may have relationship to the high crash frequency. The two intersections in Florida were selected to compare the possible influence of the "RIGHT TURNING YIELD TO PEDESTRIAN" signs on driver observation. One of the Florida intersections had the signs installed, while the other one is a similar intersection and in a similar area but without the "Yield to Pedestrian" signs. All the six intersections are signalized with four approaches. The intersection list is as the following:

1) Intersection ID: 95576, pedestrian crash (2006-2013): 18,
   Evergreen Way & Airport Rd, Everett, WA 98204 (122°15'30.44"W, 47°53'21.912"N)
2) Intersection ID: 149456, pedestrian crash (2006-2013): 16,
   Pacific Hwy & S 272nd St, Des Moines, WA 98198 (122°18'33.962"W, 47°21'28.638"N)
3) Intersection ID: 29663, pedestrian crash (2006-2013): 14,
   Lake City Way NE & NE 125th St, Seattle, WA 98125 (122°17'42.565"W, 47°43'9.335"N)
4) Intersection ID: 27821, pedestrian crash (2006-2013):14,
   Aurora Ave N & N 105th St, Seattle, WA 98133 (122°20'40.975"W, 47°42'18.223"N)
5) Intersection ID: 217545, with "RIGHT TURNING YIELD TO PEDESTRIAN" Signs

E Fowler Ave & N 50th St, Tampa, FL 33617 (82°24'6.393"W, 28°3'15.78"N)
6) Intersection ID: 213505, without "RIGHT TURNING YIELD TO PEDESTRIAN" Sign
E Fowler Ave & N 15th St, Tampa, FL 33612 (82°24'6.393"W, 28°3'15.78"N)

The SHRP 2 NDS data are subject to Federal regulations governing human subjects' research and the protection of the volunteers and their privacy. All data requests require the Institutional Review Board (IRB) approval. An IRB approval letter was obtained from the Research Integrity Office of UNR, and all researchers directly working on the NDS data received their IRB training certificates.

A total of 20 pedestrian-turning-vehicle events (crashes or close-to-crashes) were requested based on the event information on the SHRP 2 NDS InSight Data Access Website. However, only one event was provided as the other events were close to the drivers' origins or destinations. Trips close to origins or destinations may reveal the drivers' private information, therefore they were excluded from the received dataset. A total of 600 trips at the six selected intersections were received, including 50 right-turn trips and 50 left-turn trips at each intersection. Trips at each intersection were required to be from 10 or more different drivers (or the total available drivers if the available number is lower than 10) for the representative driver behavior. The length of each trip was decided by VTTI for the data security or other considerations, but each trip was no longer than 5 minutes before turning activity and no longer than 1 minute after the turning activity. The data included selected time-series data elements, driver data elements, vehicle data elements, and front videos. The time-series, driver and vehicle data elements are listed in Table 1. For the 600 trips originally received, it was found that 73 trips were not correct by reviewing the GPS coordinates and front videos. The 73 wrong trips didn't turn left or right at the studied intersections. The problem was caused by the offset or errors in the GPS locations. Additional trips were received to fill the gap and made the total valid trip number to come out to 600.

Table 1. NDS data elements for phase I study

Time Series Data		Driver	Vehicle
day_of_week	vtti.odometer	age group	model year
file_id	vtti.pedal_brake_state	gender	vehicle classification
vtti.accel_x	vtti.pedal_gas_position	education	vehicle make
vtti.accel_y	vtti.range_rate_x_tn	work status	
vtti.accel_z	vtti.range_rate_y_tn	race	
vtti.elevation_gps	vtti.range_x_tn		
vtti.heading_gps	vtti.range_y_tn		
vtti.latitude	vtti.speed_gps		
vtti.longitude	vtti.speed_network		
vtti.month_gps	vtti.timestamp		
vtti.number_of_satellites	vtti.year_gps		
vtti.object_id_tn			

As the trip length could be as long as 6 minutes (5 minutes before the turn and 1 minute after the turn), one trip may go through several intersections in addition the studied intersection. Vehicle location data and front videos were used to find the part of the trip data collected around the studied intersections. The selected segment begins at the moment (timestamp) of the vehicle starting to decelerate, and ends at the moment of the vehicle finishing turning movement at the intersection.

To study the different driver behavior during the entire turning procedure, five stages before and after a turning movement were defined:

- Stage 1: Approaching to a queue end – from the moment of the vehicle starting to slow down to the moment of stopping at a queue end at the intersection. If there is no existing queue, the end point of Stage 1 is the moment when the vehicle arrived at the stop line.
- Stage 2: Waiting in a queue – from the moment of the vehicle stopping at a queue end to the moment of re-starting to move. If there is no queue in front of the vehicle, Stage 2 could be excluded.
- Stage 3: Approaching to the stop line – from the moment of the vehicle re-starting to move to the moment of arriving at the intersection stop line. If there is no queue in front of the vehicle, Stage 3 could be excluded.
- Stage 4: Waiting at the stop line – from the moment of the vehicle arriving at the stop line (or stopped slightly before or after the stop line without other vehicles in front of it) to the moment of the vehicle starting to turn.
- Stage 5: Turning right/left – from the moment of the vehicle starting turn to the moment of finishing turning movement.

All the trip data were classified into 12 groups for the 6 intersections and the two turning movements (left/right) at each intersection. The start and end timestamps of stages were decided by analyzing the GPS log and front videos. The stage timestamps were used to extract time series data for each stage and to connect driver observation data to the stages.

Driver face video analysis was performed at the VTTI data enclave to protect the volunteers' private information. A total of 1,417 driver observation behavior records were extracted by reviewing the 600 valid trips. The observation attributes in Table 2 were recorded in the driver video analysis. Supplemental traffic condition data were extracted by analyzing the front videos. The supplemental data attributes are listed in Table 3. and the summarized numbers of valid trips and extracted observation behavior are in Table 4.

Table 2. Attributes extracted from driver face videos

Attribute	Description
File_ID	The file_id attribute of the trip record defined by VTTI
Event ID	The event_id attribute of the trip record defined by VTTI
Intersection ID	The intersection_id attribute of the intersection where the turning movement occurred
Turn	Turning direction: left turn/right turn
Begin Timestamp	The beginning timestamp for turning movement
End Timestamp	The end timestamp for turning movement
Weather	The weather condition when the turning movement occurred
Day/Night	The day/night condition when the turning movement occurred
Work Zone (Yes/No)	Whether there was a work zone at the intersection when the turning movement occurred
Sunglasses (Yes/No)	Whether the driver was wearing sunglasses
Observation ID	The ID of an observation record. Observation records of each trip start with ID number 1
Rear View Vehicle	Whether there was another vehicle following the NDS vehicle
Begin Timestamp of Observation	The beginning timestamp of an observation
End Timestamp of Observation	The end timestamp of an observation
Observation Type	The observation definitions for SHRP 2 by VTTI
Observation Target	The target of an observation, such as pedestrian, vehicle, traffic sign and traffic signal
Traffic_Signal	The traffic signal status when the vehicle arrived at the stop line
Note	Note

Table 3. Traffic condition attributes extracted from front videos

Attribute	Description
Conflicting Ped No.	The number of pedestrians who were going to cross the intersection and may conflict with the NDS vehicle
Total Pedestrian No.	The total number of pedestrians around the intersection, including the conflicting pedestrians
Yield to Pedestrian (Yes/No)	Whether the NDS driver yield pedestrians
Conflicting Traffic Direction	The conflicting traffic directions when the NDS vehicle was yielding to traffic in other directions
Conflicting Traffic Volume	The total conflicting vehicle numbers when the NDS vehicle was yielding to traffic in other directions
Conflicting Traffic Start Timestamp	The start timestamp when the NDS vehicle was yielding
Conflicting Traffic End Timestamp	The end timestamp when the NDS vehicle was yielding

Table 4. Valid trips and extracted observation records

Valid Trips											
Intersection ID	Total Trips	Left Turn Trips					Right Turn Trips				
		WS	SE	NW	EN	Total	WN	SW	NE	ES	Total
29663	100	4	39	0	7	50	18	24	5	3	50
95576	100	39	3	6	2	50	4	2	34	10	50
149456	100	24	15	4	7	50	16	5	6	23	50
27821	99	19	13	6	12	50	9	14	15	11	49
213505	99	16	0	0	34	50	44	0	0	5	49
217545	98	2	0	0	47	49	47	0	0	2	49
Total	596	104	70	16	109	299	138	45	60	54	297
Extracted Observation											
Intersection ID	Total Observation	Left Turn Observation Records					Right Turn Observation Records				
		WS	SE	NW	EN	Total	WN	SW	NE	ES	Total
29663	269	13	115	0	25	153	45	55	7	9	116
95576	289	102	21	10	6	139	10	7	101	32	150
149456	273	39	34	10	84	167	27	5	49	25	106
27821	186	38	22	10	24	94	20	30	26	16	92
213505	190	31	0	0	82	113	69	0	0	8	77
217545	186	2	0	0	84	86	97	0	0	3	100
Total	1393	225	192	30	305	752	268	97	183	93	641

4. METHODOLOGIES OF ANALYSIS

4.1 Analysis of Historical Crash Data and RID Data

Although the crash frequency has been analyzed by several existing studies, the crash data analysis was also performed for possible new findings or updates by using the Washington State data. The pedestrian-turning-vehicle crash frequency was studied for different times and dates, movement direction, severity, road conditions, driver situations and vehicle types. The frequency study is to identify the influencing factors of road, driver, vehicle and environment which were attributes included in the crash data.

4.2 Driver Observation and Influencing Factors

The extracted driver observation records include the attributes in Table 1, and the other extracted attributes related to the trips are in Table 2. A critical attribute is the observation type which were originally defined by VTTI in the "Eyeglance Definitions for SHRP2 Event and Baseline Video Reduction". Only types considered valuable for this study were selected and are listed in Table 5.

The frequency of different observation types were analyzed for the different factors and factor values (ranges). A high frequency of Type 1 through Type 7 observation are considered to be behavior helping drivers to better observe pedestrians. Type 8 to Type 17 behavior may distract drivers from their driving task and cause drivers fail to see pedestrians. High frequency of these are considered to be a higher risk for pedestrians. As observation behavior can be very different for right turning drivers and left turning drivers on the same approach of the same intersection, the observation behavior analysis was performed for right-turning and left-turning separately. Factors of turning stage, day/night (day, night, sunset/sunrise), signal condition, conflicting traffic flow, conflicting pedestrian, total pedestrian at the intersection, driver age group, driver gender, driver work status, driver education and vehicle type were analyzed to find their possible impacts on the different driver behavior.

Table 5. Observation types for driver observation study

Type 1	Left Windshield
Type 2	Right Windshield
Type 3	Rearview Mirror
Type 4	Left Window/Mirror
Type 5	Right Window/Mirror
Type 6	Left Over-The-Shoulder
Type 7	Right Over-The-Shoulder
Type 8	Instrument Cluster
Type 9	Center Stack
Type 10	Cell Phone (electronic communications device)
Type 11	iPod (or similar MP3 device)
Type 12	Interior Object
Type 13	Passenger
Type 14	No Video
Type 15	No Eyes Visible- Glance Location Unknown
Type 16	No Eyes Visible. Eyes Are Off-Road
Type 17	Eyes Closed
Type 18	Other

4.3 Index of Factor Influence on Driver Observation

The analysis introduced in Section 4.2 suggests that a change in factor values or ranges may change the driver observation behavior which may, in turn, change the pedestrian-turning-vehicle crash risk. The study also showed that changes of different factors have different effects on the behavior – positive or negative, more or less, which decide whether a factor is influencing or non-influencing. In order to quantitatively describe influence of the different factors, the index of factor influence on driver behavior was developed based on the driver observation behavior analysis. The index of factor influence, also called factor influence index, on an interesting observation type can be calculated by the following Equation (1):

$$I = \frac{\sum_{k=2}^{n} |P_k - P_{k-1}|}{n-1} \quad (1)$$

Where

I = index of factor influence on driver behavior, also called factor influence index.
k = an option of the influencing factor values or ranges.
n = the total available number of the influencing factor values or ranges.
P_k = the observation frequency percentage of the interesting observation type when the influencing factor value (or range) is k.

With index numbers calculated by Equation (1), factors can be prioritized for their influence on an observation type. An index matrix for the different factors and observation types was developed and presented in Chapter 5. The index matrix was used to generate the prioritized factor lists which have different levels of influence on the different observation types.

4.4 Crash History, Countermeasure and Driver Observation

As the four intersections in Washington State were selected for their high pedestrian crash frequency, the pedestrian-turning-vehicle crash history at the four intersections were compared with driver observation behavior to demonstrate the relationship between driver behavior and the safety performance.

The two intersections in Florida were selected to study the relationship between driver observation and the countermeasure of “RIGHT TURNING YIELD TO PEDESTRIAN” sign, which is a case study for the countermeasure influence on driver behavior. The frequencies of different observation types at the two intersections were compared, and the difference between the observation patterns were analyzed.

5. RESEARCH RESULTS

This chapter summarizes the research results from the analysis methodologies documented in Chapter 4. The results and conclusions were based on the limited dataset in the Phase 1 study which was to verify the proposed research methods. The results presented in this chapter are not recommended to be directly used in any safety evaluation or improvement projects.

5.1 Driver Observation and Influencing Factors

The influence of different factors was compared with the method as documented in Section 4.2. It was found that different factors influence driver observation behavior at different levels. One example is shown in Figure 2 which is the comparison of right-turn driver observation at different conflicting traffic flow rates. The conflicting traffic is the vehicles to which a turning driver needs to yield before the turning activity. The conflicting traffic flow is calculated by the number of conflicting vehicles by the total yielding time. The Figure 2 chart reveals that, when the conflicting traffic flow rate is between 1000 vehicle/hour and 2000 vehicle/hour, the right windshield observation has the highest frequency percent. That means drivers glance the right windshield more often than the other conflicting traffic situations and drivers can better see conflicting pedestrians. When conflicting traffic flow is higher than 2000 vehicle/hour, drivers are stressed by the busy conflicting traffic and kept watching the conflicting traffic, as there were few gaps. When the conflicting traffic flow is lower than 1000 vehicle/hour, drivers eager to check the conflicting traffic to finish turn without stop, so drivers glance left more than right. This information could be difficult to find without analysis of the driver behaviors by using the NDS data.

5.2 Factor Influence Index Matrix

The driver observation behavior analysis takes into account different factors which can be grouped into road factors, driver factors, vehicle factors and environmental factors. With the index calculation method in Section 4.3, an index matrix, Table 6, was developed for the selected factors and the observation types listed in Table 5. The Type 8 (instrument center), Type 14 (no video), Type 15 (No Eyes Visible- Glance Location Unknown), Type 16 (No Eyes Visible. Eyes Are Off-Road) and Type 17 (Eyes Closed) were excluded as there were no related observation data extracted in this study. Type 18 (Others) was also excluded. The left-turn index numbers of "conflicting pedestrian" and "total pedestrian" are not included for lack of left-turn trip data during the permissive left-turn phase. A higher index value means change of the associated factor will cause more influence on the associated driver behavior type. The index matrix can be used to evaluate the influence of different factors on an observation type. An effective countermeasure may be selected or developed by choosing the project changing factors with high index values.

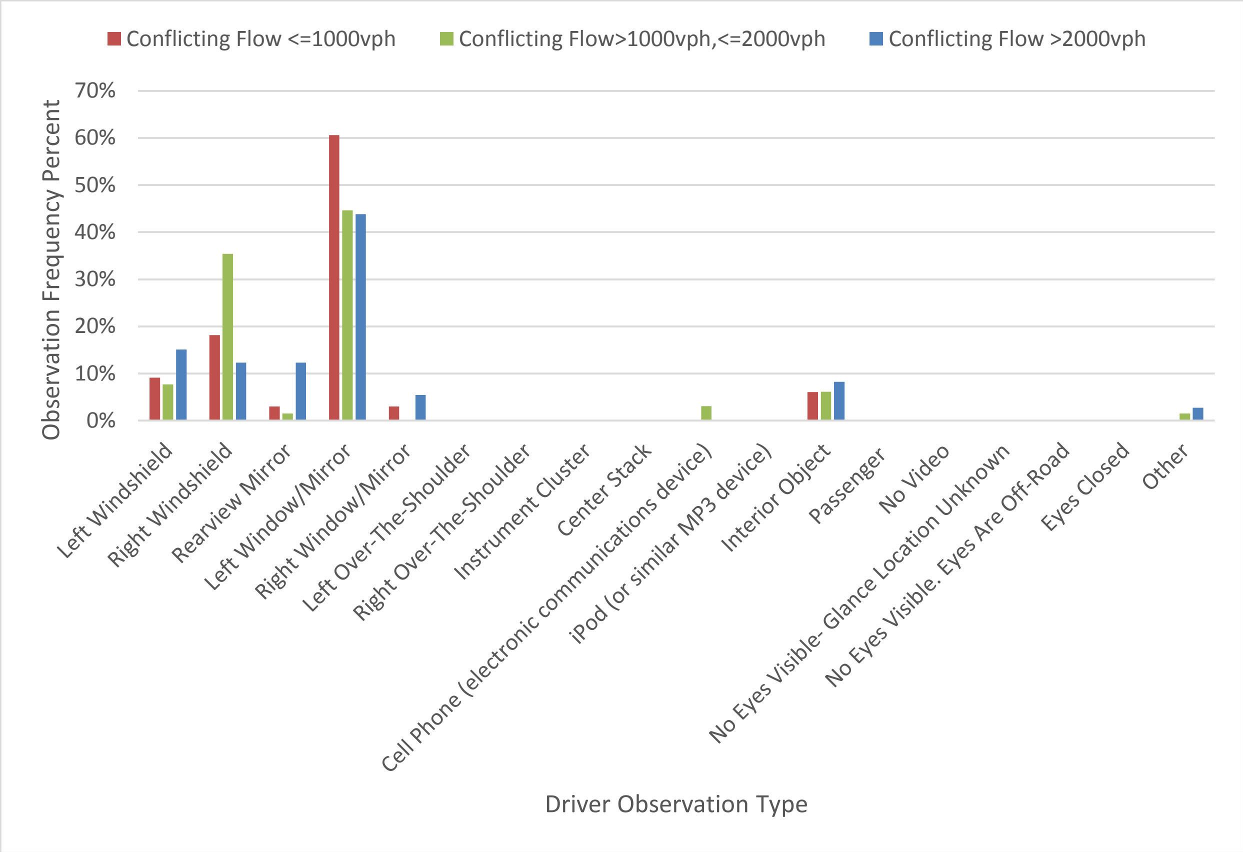

Figure 2. Driver observation with different conflicting traffic flow (right turn)

5.3 Prioritized Influencing Factors for Different Driver Observation

If a type of driver observation behavior was found to be critical for pedestrian safety at an intersection, the factors can be prioritized for influence level on this behavior. Table 7 lists the prioritized factors for left-turn drivers based on their influence indexes related to different driver behavior types, and Table 8 lists the prioritized factors for the different observation types of right-turn drivers. The first row is with the highest priority and the highest influence level, and the last row is with the lowest priority and the lowest influence level. Compared with the influence index matrix, the prioritized factors are more intuitive when being used for countermeasure selection. One example is to select countermeasures to improve right-turning drivers' right-windshield observation for pedestrian safety which is linked to the Type 2 column in Table 8. Traffic signal status (green/red) is the factor with highest influence level and priority, and the right-windshield observation frequency with green signal is much higher than the frequency with red signal. Therefore, Right-Turn-On-Red restriction or advanced pedestrian signal countermeasures will be more effective in improving drivers' right-windshield observation frequency.

Table 6. Factor influence index matrix

Factor	Turning Dir.	Behavior Types (Described in Table 5)												
		Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 9	Type 10	Type 11	Type 12	Type 13	Type 18
Time of Day	**Right**	0.0486	0.0483	0.0188	0.0650	0.0121	0.0050	0.0061	0.0011	0.0099	0.0033	0.0398	0.0055	0.0322
	Left	0.0328	0.0116	0.0262	0.0684	0.0181	0.0704	0.0095	0.0049	0.0361	0.0086	0.0507	0.0297	0.0302
Traffic Signal Status	**Right**	0.0125	0.4018	0.0472	0.2857	0.0176	0.0085	0.0010	0.0028	0.0021	0.0028	0.0745	0.0142	0.0414
	Left	0.1251	0.0185	0.0468	0.2065	0.0273	0.2269	0.0155	0.0192	0.0349	0.0039	0.0112	0.0192	0.0620
Conflicting Traffic	**Right**	0.0439	0.2013	0.0614	0.0839	0.0425	0.0000	0.0000	0.0000	0.0308	0.0000	0.0108	0.0000	0.0137
	Left	0.0729	0.0156	0.0156	0.0625	0.0104	0.0885	0.0000	0.0104	0.0365	0.0000	0.0521	0.0677	0.0729
Conflicting Pedestrian	**Right**	0.0485	0.0086	0.0328	0.0900	0.0108	0.0036	0.0167	0.0012	0.0741	0.0155	0.0478	0.0321	0.0671
	Left													
Total Pedestrian	**Right**	0.0205	0.0171	0.0183	0.0072	0.0160	0.0067	0.0067	0.0014	0.0358	0.0053	0.0230	0.0120	0.0113
	Left													
Driver Age Group	**Right**	0.0072	0.0459	0.0207	0.0272	0.0058	0.0061	0.0053	0.0030	0.0139	0.0061	0.0192	0.0143	0.0177
	Left	0.1463	0.0506	0.0480	0.0483	0.0111	0.0418	0.0075	0.0106	0.0401	0.0088	0.1683	0.0191	0.0663
Driver Gender	**Right**	0.0074	0.0719	0.0426	0.0378	0.0107	0.0019	0.0008	0.0028	0.0169	0.0044	0.0095	0.0011	0.0016
	Left	0.0849	0.0006	0.0512	0.0208	0.0040	0.0074	0.0091	0.0059	0.0139	0.0068	0.0919	0.0074	0.0095
Driver Work Status	**Right**	0.0272	0.0484	0.0303	0.0654	0.0357	0.0057	0.0082	0.0021	0.0147	0.0041	0.0364	0.0045	0.0241
	Left	0.1219	0.0384	0.0426	0.0403	0.0483	0.0053	0.0129	0.0194	0.0269	0.0129	0.1456	0.0053	0.0692
Driver Education	**Right**	0.0269	0.1080	0.0124	0.1346	0.0144	0.0077	0.0035	0.0026	0.0066	0.0035	0.0250	0.0067	0.0209
	Left	0.1362	0.0459	0.0372	0.0595	0.0137	0.0389	0.0038	0.0075	0.0447	0.0071	0.0702	0.0133	0.0705
Vehicle Type	**Right**	0.0637	0.0036	0.0376	0.0394	0.0094	0.0200	0.0041	0.0020	0.0265	0.0061	0.0239	0.0102	0.0202
	Left	0.0375	0.0156	0.0389	0.0216	0.0006	0.0473	0.0160	0.0067	0.0281	0.0178	0.0418	0.0115	0.0500

Table 7. Prioritized influencing factors for left-turn drivers

	Observation Types (Described in Table 5)											
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 9	Type 10	Type 11	Type 12	Type 13
Prioritized Factors	Driver Age Group	Driver Age Group	Driver Gender	Traffic Signal Status	Driver Work Status	Traffic Signal Status	Vehicle Type	Driver Work Status	Driver Education	Vehicle Type	Driver Age Group	Conflicting Traffic
	Driver Education	Driver Education	Driver Age Group	Time of Day	Traffic Signal Status	Conflicting Traffic	Traffic Signal Status	Traffic Signal Status	Driver Age Group	Driver Work Status	Driver Work Status	Time of Day
	Traffic Signal Status	Driver Work Status	Traffic Signal Status	Conflicting Traffic	Time of Day	Time of Day	Driver Work Status	Driver Age Group	Conflicting Traffic	Driver Age Group	Driver Gender	Traffic Signal Status
	Driver Work Status	Traffic Signal Status	Driver Work Status	Driver Education	Driver Education	Vehicle Type	Time of Day	Conflicting Traffic	Time of Day	Time of Day	Driver Education	Driver Age Group
	Driver Gender	Vehicle Type	Vehicle Type	Driver Age Group	Driver Age Group	Driver Age Group	Driver Gender	Driver Education	Traffic Signal Status	Driver Education	Conflicting Traffic	Driver Education
	Conflicting Traffic	Conflicting Traffic	Driver Education	Driver Work Status	Conflicting Traffic	Driver Education	Driver Age Group	Vehicle Type	Vehicle Type	Driver Gender	Time of Day	Vehicle Type
	Vehicle Type	Time of Day	Time of Day	Vehicle Type	Driver Gender	Driver Gender	Driver Education	Driver Gender	Driver Work Status	Traffic Signal Status	Vehicle Type	Driver Gender
	Time of Day	Driver Gender	Conflicting Traffic	Driver Gender	Vehicle Type	Driver Work Status	Conflicting Traffic	Time of Day	Driver Gender	Conflicting Traffic	Traffic Signal Status	Driver Work Status

Table 8. Prioritized influencing factors for right-turn drivers

	Observation Types (Described in Table 5)											
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 9	Type 10	Type 11	Type 12	Type 13
Prioritized Factors	Vehicle Type	Traffic Signal Status	Conflicting Traffic	Traffic Signal Status	Conflicting Traffic	Vehicle Type	Conflicting Pedestrian	Driver Age Group	Conflicting Pedestrian	Conflicting Pedestrian	Traffic Signal Status	Conflicting Pedestrian
	Time of Day	Conflicting Traffic	Traffic Signal Status	Driver Education	Driver Work Status	Traffic Signal Status	Driver Work Status	Traffic Signal Status	Total Pedestrian	Vehicle Type	Conflicting Pedestrian	Driver Age Group
	Conflicting Pedestrian	Driver Education	Driver Gender	Conflicting Pedestrian	Traffic Signal Status	Driver Education	Total Pedestrian	Driver Gender	Conflicting Traffic	Driver Age Group	Time of Day	Traffic Signal Status
	Conflicting Traffic	Driver Gender	Vehicle Type	Conflicting Traffic	Total Pedestrian	Total Pedestrian	Time of Day	Driver Education	Vehicle Type	Total Pedestrian	Driver Work Status	Total Pedestrian
	Driver Work Status	Driver Work Status	Conflicting Pedestrian	Driver Work Status	Driver Education	Driver Age Group	Driver Age Group	Driver Work Status	Driver Gender	Driver Gender	Driver Education	Vehicle Type
	Driver Education	Time of Day	Driver Work Status	Time of Day	Time of Day	Driver Work Status	Vehicle Type	Vehicle Type	Driver Work Status	Driver Work Status	Vehicle Type	Driver Education
	Total Pedestrian	Driver Age Group	Driver Age Group	Vehicle Type	Conflicting Pedestrian	Time of Day	Driver Education	Total Pedestrian	Driver Age Group	Driver Education	Total Pedestrian	Time of Day
	Traffic Signal Status	Total Pedestrian	Time of Day	Driver Gender	Driver Gender	Conflicting Pedestrian	Traffic Signal Status	Conflicting Pedestrian	Time of Day	Time of Day	Driver Age Group	Driver Work Status
	Driver Gender	Conflicting Pedestrian	Total Pedestrian	Driver Age Group	Vehicle Type	Driver Gender	Driver Gender	Time of Day	Driver Education	Traffic Signal Status	Conflicting Traffic	Driver Gender
	Driver Age Group	Vehicle Type	Driver Education	Total Pedestrian	Driver Age Group	Conflicting Traffic	Conflicting Traffic	Conflicting Traffic	Traffic Signal Status	Conflicting Traffic	Driver Gender	Conflicting Traffic

5.4 Pedestrian-Turning-Vehicle Crash Frequency and Driver Observation

Figure 3 shows the frequencies of different observation types at the four intersections. Figure 4 is the pedestrian-turning-vehicle crashes that occurred at the four intersections in Washington during 2006 -2013. The crash data were classified by the vehicle turning movements – right turn and left turn. Figure 4 shows high pedestrian-right-turning-vehicle crash frequency at the intersection 149456, and Figure 3 shows the low "Right Windshield" observation frequency at the same intersection. The right observation frequency at the intersection of 27821 is lower than intersections of 29663 and 95576, while its pedestrian-right-turning-vehicle crash frequency is higher than the other two intersections. The comparative study of crash frequency and behavior shows the connection between the pedestrian crash frequency and the frequency of specific observation types. However, it should be noted that this conclusion is based on limited data at the four intersections. More accurate description of the relationship needs to be developed in Phase 2 study with sufficient NDS data.

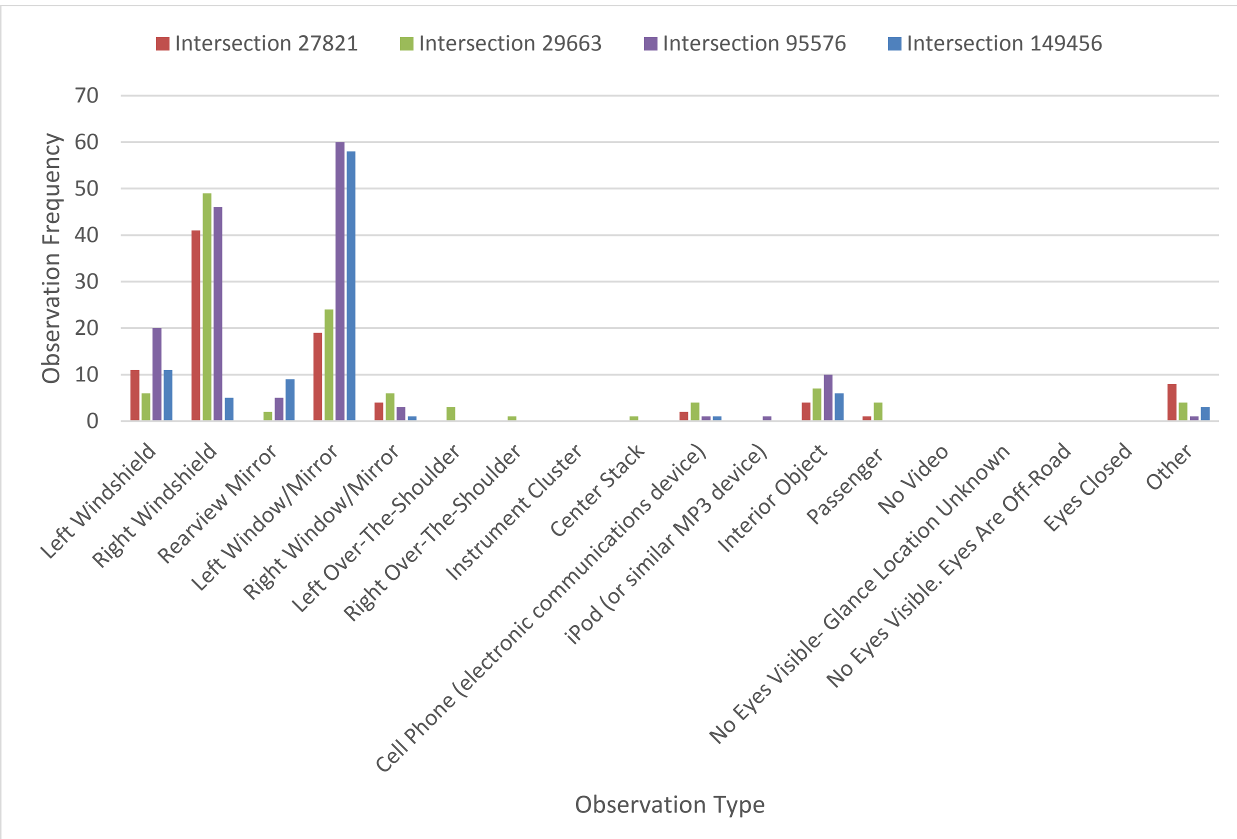

Figure 3. Observation frequency at the four intersections in Washington (right turn)

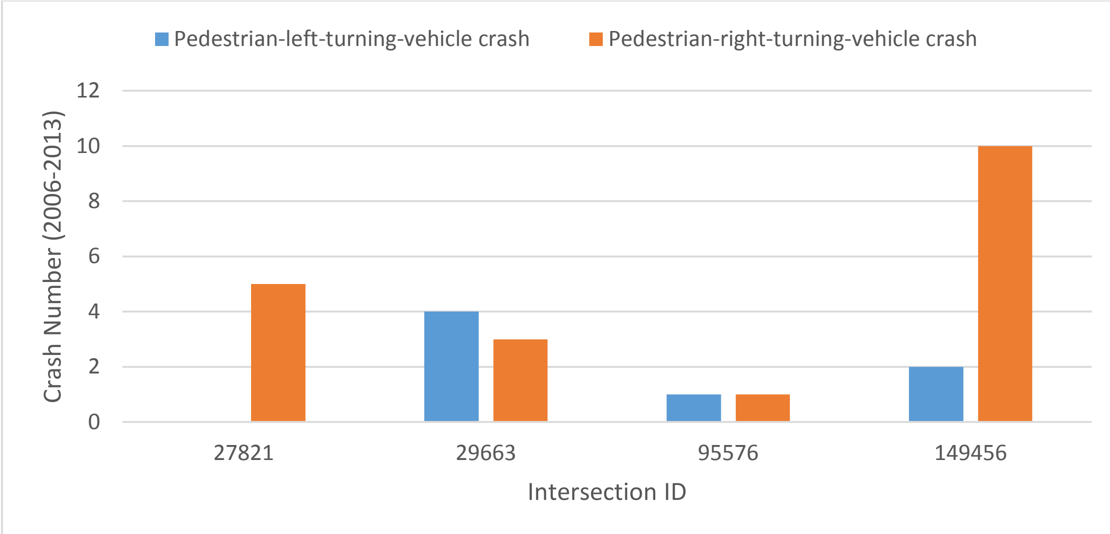

Figure 4. Pedestrian-turning-vehicle crash frequency at the four intersections in Washington

5.5 Influence of a Countermeasure on Driver Observation

The comparison of driver behavior at the two Florida intersections is presented in Figure 5. Intersection 217545 has the "RIGHT TURNING YIELD TO PEDESTRIAN" signs installed, while Intersection 213505 does not have. The chart shows that right-turning drivers have higher right windshield observation frequency and higher left windshield observation frequency at Intersection 217545 than at intersection 213505. Aince the other attributes of the two intersections were similar, it is reasonable to conclude that the traffic signs encouraged drivers to check both direction more often, which can reduce the risk of pedestrian-turning vehicle crashes.

5.6 Summary

The Phase 1 study completed the following tasks:

- analyzed the influence of different factors on driver observation behavior;
- developed the quantitative description method, factor influence index, for the influence level;
- created the factor influence index matrix and prioritized factor lists;
- demonstrated the relationship between driver observation behavior and pedestrian crash type/frequency;
- demonstrated the relationship between driver observation behavior and a countermeasure .

The results were based on the limited NDS data size, so they are not recommended for countermeasure selection and development in real projects. However, the results of this project affirmed the research approach.

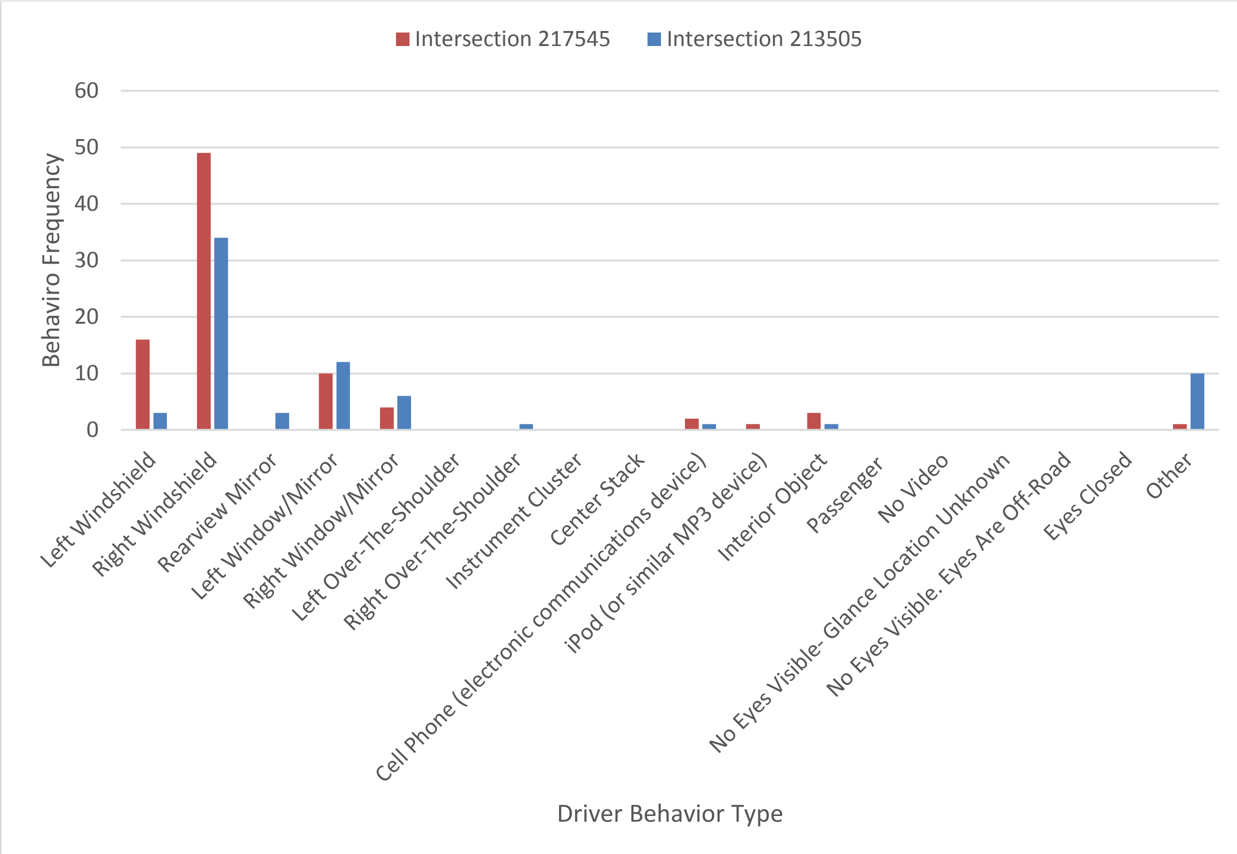

Figure 5. Influence of "RIGHT TURNING YIELD TO PEDESTRIAN" signs on driver observation

6. FUTURE DIRECTION

The future research direction will be to extend the current results and findings with additional NDS data and analysis. For the factor influence index matrix development and factor prioritization, different index matrixes will be developed for different intersection types with consideration of the critical intersection attributes, such as traffic control, approach number, intersection AADT and area type (urban vs. rural). The index matrix developed in the Phase 1 project included limited road properties, more will be addressed in the future research such as lane configuration and grade. The final product of this task will be factor influence index matrixes and prioritized lists of different intersection types which will be an input of the countermeasure selection procedure proposed in Figure 6.

To extend the study on relationship of intersection crash frequency/severity and driver behavior trend, the analysis will also be for different intersection types. For each type, driver observation behavior will be analyzed for different crash frequency, severity and location. Driver observation pattern related to the different safety performance will be studied, and the crash-observation relationship will be the final product of this task. The relationship can be used to identify the driver behavior to improve for high-crash intersections. It is also an input of the proposed procedure in Figure 6.

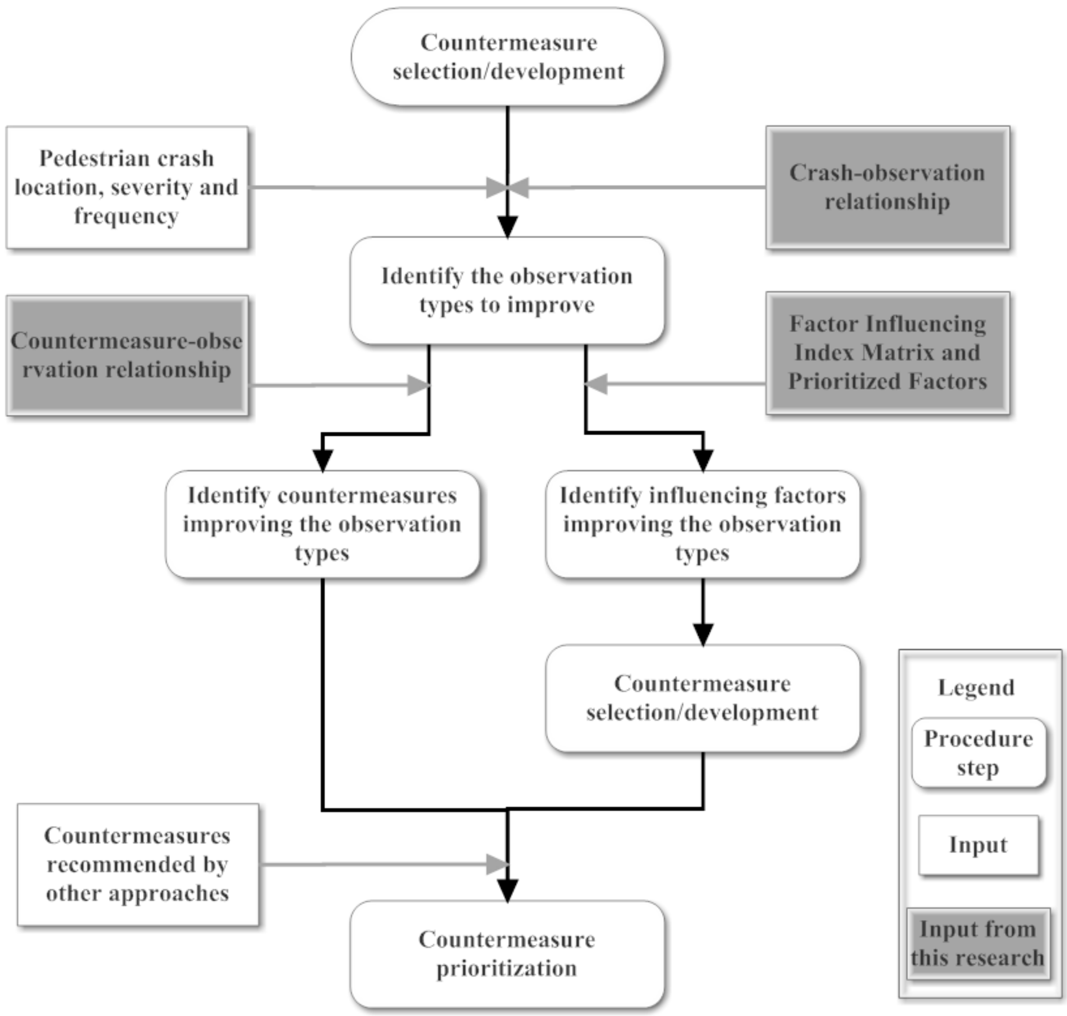

Figure 6. Proposed procedure for countermeasure selection/development with the proposed research results

The relationship between driver behavior and countermeasures will also be studied for the different intersection types. For each selected countermeasure, treated sites and non-treated sites will be both identified to learn the countermeasure's impact on the different driver observation. The relationship between countermeasures and driver observation will be the product for this task, and used to select the countermeasures for improvement of driver observation. Limited by the size of NDS road network, not all countermeasures can be included in the relationship knowledge set. For those countermeasures without known relationship to driver behavior, they can still be evaluated or selected with consideration of the factor index matrixes. The three products - index matrixes, crash-observation relationship and countermeasure-observation relationship – will be used to select countermeasures for pedestrian safety by the proposed procedure in Figure 6.

7. PHASE 2 PROPOSAL

The research objectives of the Phase 2 study are listed in the following:

- To extend the driver observation behavior analysis to include more factors and different intersection types.
- To extend the factor influence index matrixes by including more factors for different intersection types.
- To develop the crash-observation relationship at different types of intersections
- To develop the countermeasure-observation relationship at different types of intersections.
- To develop countermeasure selection guidance with consideration of driver behavior. Scenarios of selecting/developing countermeasures for selected high-pedestrian-crash intersections will be included as examples.

7.1 Data Needs

The Phase 2 will need the same time-series data attributes, front videos and the driver videos as the Phase 1 study. The same driver data and vehicle data will also be requested. The data size will be much larger and from all the six NDS data collection sites. The research team understands that the driver video analysis needs to be performed at the data enclave room at VTTI. The detailed trip number to be requested will be decided after identification of intersection types and influencing factors. The data size is expected to be more than 20,000 trips at more than 100 intersections.

7.2 Refined Research Approach

Driver observation data and related traffic conditions will be extracted from the driver videos and front videos. The extracted data from videos will be integrated with the time-series data and RID data based on the timestamps and locations. Additional road properties will be studied for their influence on driver observation behavior and included in the final influence index matrixes. The developed index matrixes and relationships will be for specific intersection types. The major research tasks for the Phase 2 are as follows:

1) Identification of intersections and additional factors

The Phase 2 study will start with analysis of the six-site RID data. The RID road/intersection property layers will be integrated by the linear referencing system. The integrated road and intersection data will be used to decide the intersection types for index matrix development and relationship study. Intersection type will be decided based on critical intersection properties, such as traffic control, approach number, AADT and area type. The road properties in the integrated dataset will be included in the analysis of influence on driver observation. Crash data will be queried to find the crash frequency, severity and location related to the different intersection types. Candidate intersections for crash-observation relationship development will be identified based on the intersection crash data. This step will also identify sites with typical countermeasures installed for intersection pedestrian safety. Similar intersections without countermeasures will also be identified for comparison analysis.

2) Data request and processing

The data request will be prepared based on the intersection and factor identification results of Task 1. It is known that the NDS trip data can be very limited at some intersections. Extra candidate intersection sites will be selected for each intersection type for sufficient NDS data. The requested data attributes will be the same as in the data request for Phase 1, but the size will be much larger and include all the six NDS sites. Driver observation behavior data will be extracted at the VTTI data enclave. The other trip data, such as conflicting traffic information and pedestrian numbers, will be extracted from front videos. The data extracted from videos will be linked to the time-series data by the timestamps. The road property data will also be integrated with the observation behavior by the location information.

3) Data analysis

With the integrated data set, influence of different factors on driver behavior will be analyzed. The analysis will be conducted for the different intersection types. The frequency percentage of different observation types will be analyzed to understand factor influence on drivers. The observation frequency percentage will also be used to develop the factor influence index matrixes. The data analysis will be extended to find the combined influence of multi factors. Statistical analysis and regression methodologies are planned for the factor combination. Data mining algorithms will also be applied.

Data related to intersections with countermeasures will be used to analyze the effect of different countermeasures on driver observation. The data will be compared with similar sites without countermeasures. The countermeasure evaluation is expected to advance understanding of the effect of different countermeasures, and developing the countermeasure-observation relationship. The trip and observation data at intersections with different crash frequency and severity will be analyzed, so the observation pattern related to the different safety performance can be developed.

4) Recommendation on countermeasure selection and development

With the developed influence index matrixes, crash-observation relationship and countermeasure-observation relationship, a guidance for countermeasure selection/development will be provided based on the procedure in Figure 6. Three intersections with high pedestrian crash frequency will be selected to demonstrate the countermeasure selection. The countermeasure selection for the three intersections will be based on the products and procedure developed in this project.

7.3 Institutional Review Board (IRB) Compliance

The research team understands the responsibility of protecting the rights and welfare of human research participants for all research activities. In the whole project term, the team will comply with the policy and procedures for the protection of human subjects of research. All team members who will work on the SHRP 2 Safety Data have received IRB training certificates. Application for approval of research with human subjects will be submitted before requesting or studying any PII data. Data sharing agreement will be submitted for IRB review for data request. All the obtained SHRP 2 Safety Data will be encrypted following related policy and the data sharing agreement. The PI will be responsible for IRB compliance of this research team.

7.4 Project Schedule

Phase 2 study is planned as a two-year project. The proposed project schedule for Phase II is shown in Appendix A.

7.5 Project Budget

The estimated total budget for Phase II is $298,620. The itemized budget for Phase II is listed in Appendix B.

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APPENDIX A. PROJECT SCHEDULE

	Task	Start	End
	Concept to Countermeasure - Research to Deployment Using the SHRP2 Safety Data - Phase 2	1/1/16	12/31/17
1	Project management	1/1/16	12/31/17
2	RID data analysis and influencing factor identification	1/1/16	4/30/16
3	Data request and processing	3/1/16	2/28/17
4	Data analysis	11/1/16	7/31/17
5	Recommendation on countermeasure selection and development	7/1/17	10/30/17
6	Documentation of results	9/1/17	12/31/17

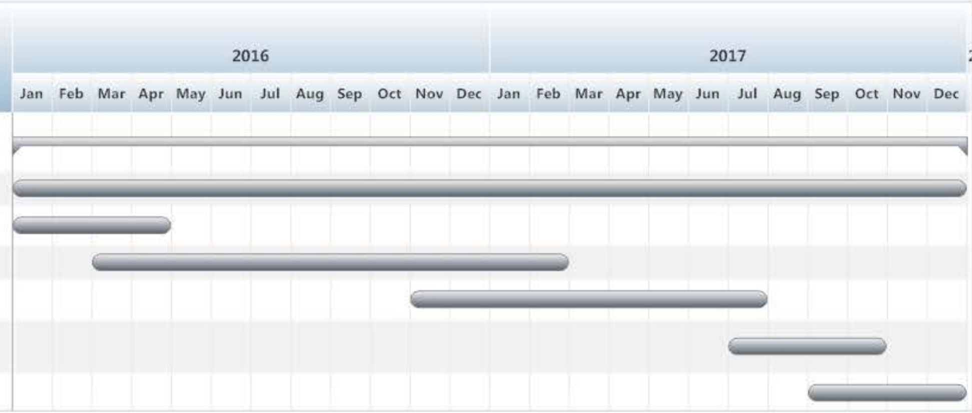

Figure A.1 Phase 2 Schedule

APPENDIX B. PROJECT BUDGET

Table B.1 Phase 2 Budget

Project Title: Concept to Countermeasure - Research to Deployment Using the SHRP2 Safety Data - Phase 2 **Project Duration:** 24 months					
Name	Position	% Fringe Benefit	Per Hour	Total Hour	Total
Xu	Professional	17%	$ 70	300	$ 21,074
Tian	Professional	17%	$ 82	80	$ 6,591
Teng	Professional	17%	$ 82	80	$ 6,591
Reider	Professional (LOA)	10%	$ 69	150	$ 10,313
TBD	Graduate	15%	$ 26	2500	$ 64,688
TBD	Undergraduate	2%	$ 18	1200	$ 21,420
A. Personnel					$ 130,676
B. Travel					$ 8,000
C. Operating Costs					$ -
D. Publications					$ -
E. SHRP 2 Safety Data request cost					$ 100,000
F. Subtotal of Direct Costs (Sum of A thru E)					$ 238,676
G. Total Indirect (% of F at 23%)					$ 54,895
H. Permanent Equipment>$1,000 (including computers)					$ -
I. Student Tuition and Fees					$ 5,049
J. Contractor >$1,000					$ -
K. Total Project Costs (sum of F thru J)					$ 298,620

Nevada Department of Transportation
Rudy Malfabon, P.E. Director
Ken Chambers, Research Division Chief
(775) 888-7220
kchambers@dot.nv.gov
1263 South Stewart Street
Carson City, Nevada 89712