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Integrating CRASH, Hospital, and Roadway Data to Investigate the Effect of Cable Median Barriers on Injury Severity

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Kentucky Transportation Center
College of Engineering, University of Kentucky Lexington, Kentucky

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Commonwealth of Kentucky

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Kentucky Transportation Center • University of Kentucky
176 Raymond Building • Lexington KY 40506 • 859.257.6898 • www.ktc.uky.edu

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Research Report
KTC-18-21/M3DA-18-02-1F

Integrating CRASH, Hospital, and Roadway Data to Investigate the Effect of Cable Median Barriers on Injury Severity

Michael Singleton, Ph.D.
Kentucky Injury Prevention and Research Center

Eric Green, Ph.D.
Research Engineer

William Staats, MSCE
Research Engineer

and

I-Chen Chen, Ph.D.
Kentucky Injury Prevention and Research Center

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

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Executive Summary

- In median-involved crashes, the odds of a police-reported injury were estimated to be 42% lower on road segments with a cable median barrier (CMB) than on road segments with a concrete median barrier, and the difference was statistically significant [odds ratio 0.58, 95% confidence interval (0.43, 0.78)].
- In median-involved crashes, the odds of having an injury severity score of 8 or greater were estimated to be 34% higher on road segments with a CMB than on road segments with a concrete median barrier; however, the difference was not statistically significant [odds ratio 1.34, 95% confidence interval (0.67, 2.66).
- In median-involved crashes, the odds of having a police-reported injury were estimated to be 48% lower on road segments with a CMB than on road segments with a no median barrier; however, the difference was not statistically significant [odds ratio 0.52, 95% confidence interval (0.20, 1.31).
- In median-involved crashes, the odds of having an injury severity score of 4 or greater were estimated to be 65% lower on road segments with a CMB than on road segments with a no median barrier; however, the difference was not statistically significant [odds ratio 0.35, 95% confidence interval (0.04, 3.02).
- Sample size (numbers of vehicles and occupants involved in median-involved crashes for each median barrier type) was smaller than anticipated, resulting in low statistical power to assess differences in injury risk for different median barrier types.
- The findings raise the possibility that in some cases conclusions based on physician-based injury severity measures differ from conclusions based on police-reported injury severity measures
- The question of differences in police- vs. physician-reported injury severity measures bears further investigation using approaches that address lessons learned from this pilot study.
- This study did not address the question of which type of median barrier is most effective at preventing crashes altogether; it only assessed the risk of injury in crashes that occurred and were reported by police

Background

Kentucky annually integrates roadway and crash data so that roadway geometric information can be linked with crash details. This helps the state determine what engineering solutions might be warranted. Moreover, this roadway information can inform regression models that help predict crashes. Most of Kentucky's roadway data are contained in the Highway Information System (HIS). This includes lane widths, crosswalks, curvature, and other roadway features. Many of these features have been analyzed for their relationship to crash occurrence — but only using the police-reported KABCO injury severity scale.

Crashes are also annually linked to hospital and emergency department records to understand more about injuries associated with crashes. The Crash Outcome Data Evaluation System (CODES) has been very successful in making this linkage for many years across the nation. It allows for much more detailed injury information, including physician diagnoses, medical procedures performed, and charges billed for treatment.

Moreover, Kentucky has recently started maintaining other roadway information databases, such as the intersection database and a database the houses the location of safety improvements. By integrating CRASH, roadway, and injury databases, for example, the intersection database could be used to analyze detailed injury outcomes among different intersection configurations (3-legs vs. 4-leg; signalized vs. non-signalized). Similarly, the effectiveness of roadway safety features, such as cable barriers, rumble strips, and high friction surfaces, at reducing nonfatal injury severity and preventing specific injury types could be analyzed.

The purpose of this project was to demonstrate the utility of integrated CRASH, roadway, and injury databases for improving traffic safety.

Project Aims

1. Use Kentucky's cable median barrier (CMB) database and Highway Management Information System (HMIS) database to identify road segments with installed CMBs and matching road segments with either concrete median barriers or no median barriers.
2. Use the linked CRASH-roadway-injury database to assess the impact of CMBs on the reduction of injury severity by comparing injury severity on road segments with CMBs to road segments with either concrete median barriers or no median barriers.
3. Produce a report on the impact of CMBs on injury severity.

Methods

Data Sources

Crash Outcome Data Evaluation System (CODES) Data

Physician injury diagnosis codes and injury severity scores for 2008-2014 were obtained from the Kentucky CODES system. Through CODES, CRASH data are linked annually with hospital inpatient discharge and emergency department visit records collected by the Kentucky Cabinet for Health and Family Services.

Cable Median Barrier Database

The Kentucky Transportation Center (KTC) recently completed an in-service evaluation of CMB effectiveness in Kentucky. As a part of this research, the installation and maintenance records for all CMBs in the state were obtained from the Kentucky Transportation Cabinet's (KYTC) 12 Highway District Offices. Installation records were compiled into a uniform, statewide database containing information on the location, project letting date, installation date, and cost of all CMBs in Kentucky (Howell et al. 2017). This database was used to identify CMB locations for a more detailed injury analysis.

Highway Information System

KYTC maintains a database of various roadway attributes for state-maintained roads in its Highway Information System (HIS). These roadway attributes are stored in GIS shapefiles, which are available for public download. Some of the attributes pertinent to this project included the median shapefile, which contains information on median widths and median barrier types; the shoulder shapefile, which contains information on shoulder widths and locations; and the through lanes shapefile, which contains information on the number of lanes and lane widths. These shapefiles were used to create segments with uniform roadway characteristics.

KYTC Photolog

Another useful tool created and maintained by KYTC is its Photolog database. It combines all of the roadway attribute information from the HIS database into an online, interactive map format. In addition to combining the roadway attribute databases into a single map, Photolog also provides street view photographs of all state-maintained roads in 26-ft. increments. This allows users to determine a roadway's attributes and see a driver's perspective of the road by selecting roadways either from an aerial map or by entering specific roadway location information. Figure 1 shows an example of the Photolog database user interface.

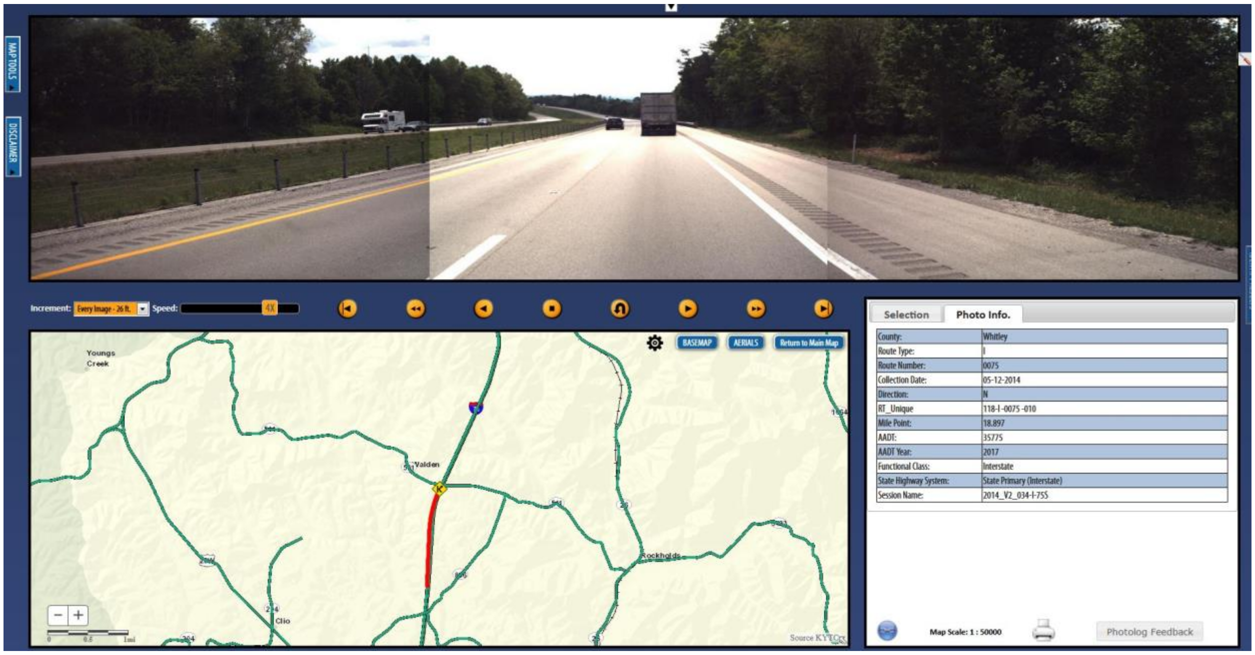

Figure 1 KYTC Photolog User Interface

Photolog contains roadway attribute and imagery data for both the cardinal (increasing milepoint) and non-cardinal (decreasing milepoint) directions of a roadway. Therefore, a user could simulate driving both directions of a divided highway by starting at a single location and proceeding to the next 26-ft. increment.

Study Design

This cross-sectional study compared injury outcomes for individuals involved in traffic crashes on road segments with a CMB to injury outcomes for people involved in crashes on a) segments with no median barrier, and b) segments with a concrete median barrier. CMBs were identified from an existing database and divided into segments that were uniform with respect to road features that might influence injury severity. For each cable segment, a matching road segment with similar characteristics — but having either no barrier or a concrete median barrier — was identified as described below. Occupants involved in crashes on each road segment were identified from the Kentucky CRASH database. Injury severity scores based on physician injury diagnoses were obtained for each occupant from the Kentucky CODES database.

Partitioning of Cable Median Barrier into Uniform Road Segments

The CMB database from the previous KTC project was used to identify locations in Kentucky with CMBs. The CMB database has a beginning and end milepoint for each CMB installation project, but the CMBs are not continuous along the entire project length. CMBs typically end slightly before interchanges and overpasses and begin again on the other side. Therefore, the research team excluded from analysis these short segments where CMBs were not present. These short segments without CMBs were identified during the identification of CMB segments with homogenous roadway characteristics.

The database of CMB installations was segmented by direction based on number of lanes, shoulder width, median barrier offset, median width, CMB location, and right-side barrier type. This means that for each CMB location in the database, each direction of the divided roadway was segmented any time one of the roadway attributes above changed in a significant manner (i.e., small changes in median width did not result in a new segment). Changes in these roadway attributes were identified using the following process:

1. Starting with the CMB database with the general beginning and end milepoints of a CMB installation.
2. For each CMB installation in the database, navigate to the beginning milepoint in Photolog and record the following roadway attributes: number of lanes, shoulder width, median barrier offset, median width, CMB location, and right-side barrier type
3. Virtually progress down the road in the cardinal direction using Photolog until one of the attributes listed in step 2 changes, or until a CMB segment ends before an overpass or begins after an overpass. Record the milepoint where the attribute changes as the segment's end milepoint; start a new segment with a beginning milepoint that has the same ending milepoint of the previous segment.
4. Continue repeating Step 3 until the ending milepoint of the CMB installation listed in the CMB database is reached (from Step 1).
5. Repeat Steps 2-4 for the non-cardinal direction of the divided roadway.

Instances where overpasses are present along a CMB installation and result in the CMB being discontinuous were identified with this process and removed from the injury study. This process resulted in two tables of uniform CMB segments: one for the cardinal direction and one for the non-cardinal direction. Table 1 is an example of uniform CMB segments for the cardinal direction.

Table 1 Uniform CMB Segments in the Cardinal Direction

Route	Beginning milepoint	Ending milepoint	# Lanes	Shoulder Width	Median Barrier Offset	Location of CMB	Median Width	Right Side Barrier Type
056-I - 0071 -000	5.571	6.149	4	8	30	Non-Cardinal	35	Metal Guardrail
056-I - 0071 -000	6.149	6.255	Overpass					
056-I - 0071 -000	6.255	6.345	4	8	5	Cardinal	35	Metal Guardrail
056-I - 0071 -000	6.345	6.436	4	8	5	Cardinal	35	Rock Cliff Face
056-I - 0071 -000	6.436	6.557	4	8	5	Cardinal	35	Earth Embankment
056-I - 0071 -000	6.557	6.647	4	8	30	Non-Cardinal	35	Earth Embankment

056-I - 0071 -000	6.64 7	6.68 2	4	8	30	Non-Cardinal	35	Rock Cliff Face

In total, there were 1,122 cardinal direction CMB segments and 1,305 non-cardinal direction CMB segments (about 280 miles per direction) in the state of Kentucky that were uniform with respect to number of lanes, shoulder width, median barrier offset, median width, CMB location, and right-side barrier type.

Identification of Comparable Control Segments

The control segment for each uniform CMB segment needs to have similar roadway attributes as the CMB segment, but without a CMB. To identify control segments for the uniform CMB segments, the remaining interstates and parkways in Kentucky that were identified as not having CMBs were segmented in a similar manner to the CMB locations. The only modification to the previous methodology is the addition of a new roadway attribute, median barrier type. This new attribute accounts for all median barrier types other than CMB, including no median barriers, guardrails, concrete barriers, and natural barriers (rock cliff faces and trees). This process resulted in 1,770 cardinal direction non-CMB and 1,521 non-cardinal non-CMB uniform segments to be used as potential control segments.

Control segments were matched to uniform CMB segments with similar roadway attributes. Matches were processed by geographic location, meaning CMB segments near large cities were matched to non-CMB segments near large cities to provide similar traffic exposure and driving characteristics. Likewise, rural, lower volume CMB segments were matched with rural, lower volume non-CMB segments. Aside from geographic location, segment length, number of lanes, and median barrier offset were prioritized as the most important attributes to match when selecting a control segment, as these attributes were deemed most likely to affect the number of median barrier-related crashes on a segment.

Not all CMB segments could be matched because a similar non-CMB segment was not available in all cases. In total, 842 cardinal direction and 881 non-cardinal direction CMB/non-CMB pairs were matched.

Variables

Median-Involved Crash

Of interest in this study were crashes in which a vehicle either entered the median or would have entered the median if a median barrier had not been present. The median-involved crashes analyzed in this study were identified by querying annual crash extracts from KSP. Crashes that occurred between the beginning and end milepoints of the routes for any of the matched segments were identified as median-involved if the crash report was coded as a median crossover crash; the location of the first event of the crash was on the median or left shoulder; the manner of collision was angle, head-on, or sideswipe opposite direction; or if the directional analysis code was head-on collision or sideswipe collision in the opposite direction:

- Median Crossover Indicator = Y
- Location of first event = Median (02) or Outside Shoulder, Left (04)
- Directional Analysis = Head-on Collision (52) or Sideswipe Collision - Opposite Direction (54)
- Manner of collision = Angle (01) or Head On (03) or Sideswipe, Opposite Direction (07)

Police-Reported Injury Severity

Police report injury severity on the KABCO scale as killed (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and no apparent injury (O). Classification is based on the opinion of the investigating officer based on evidence observable at the crash scene. For the purpose of this report, an occupant was considered to have a police-reported injury if the KABCO score was K, A, or B.

Hospital-Based Injury Severity Score

The Injury Severity Score (ISS) is based on diagnoses recorded by the attending physician at the hospital where an individual was treated. This information was obtained from the hospital billing record that was linked to the CRASH record in the CODES database. If a patient received both ED and inpatient treatment, the inpatient diagnoses were used to calculate ISS. Scores range from 0 for a patient with no physician-diagnosed injuries to a maximum of 75. Each diagnosed injury is assigned to one of 6 body regions and assigned a severity level ranging from 1 (minor injury) to 6 (unsurvivable injury). The body regions are head/neck, face, chest, abdomen, extremities, and external. The maximum severity injury for each body region is determined and ranges from 0 (no injury) to 6 (unsurvivable injury). If any region has a maximum injury severity of 6, the ISS is 75. Otherwise, the highest 3 body region-specific maximum injury scores are squared and summed. If the sum exceeds 75, the patient is assigned a score of 75.

In traffic crash patient populations, most ISS scores tend to be small, reflecting the fact that most patients have relatively minor injuries. Various thresholds for severe injuries based on ISS have been proposed (Brown et al. 2017; Palmer et al. 2016; Palmer 2007). For the purposes of this study — and largely due to the modest number of hospital-treated occupants in our sample — we defined two thresholds: ISS greater than or equal to 4 and ISS greater than or equal to 8. Higher cutoffs have been proposed for various populations. Discussions of the calculation, interpretation, and limitations of the ISS can be found in Baker et al. (1974), Baker and O'Neill (1976), and Wayne et al. (1988).

Statistical Analysis of Association Between Cable Median Barrier and Injury Risk

Traffic crash data are multilevel, with occupants nested within vehicles nested within crashes nested within road segments. This nesting creates a situation in which occupant injury outcomes cannot be treated as independent. For example, occupants of the same vehicle will tend to have similar levels of injury because all are subjected to similar forces. Several approaches exist for modeling this hierarchical structure; several of these were compared and contrasted in a recent paper (Usman et al. 2016).

To account for the nesting of occupants, we modeled the odds of injury for occupants involved in median-involved crashes on road segments with a CMB using Generalized Estimating Equations (GEE) with robust standard error estimation (Liang and Zeger 1986). Occupant and vehicle characteristics that might influence injury risk, independent of median barrier type, were included in the GEE models to adjust for differences in the characteristics of CMB segments from the concrete and no-barrier segments. Characteristics included in the models were occupant age, gender, restraint use, ejection status, vehicle rollover, and vehicle type (passenger vehicle vs. light truck).

CRASH File Narrative Review for Information on Occupant Transport to Hospital

The research team manually reviewed crash reports for all identified median-involved crashes on the matched pairs selected for the study. Each crash report contains a narrative field, where an officer writes a statement describing the crash, and fields to indicate EMS involvement. These report fields were used to determine if a crash involved an injury that required a person to be transported to a hospital/trauma center and where that hospital/trauma center was located. Two flags were created during this process: one for an injured person transported to a medical treatment facility in Kentucky and another if an injured person was transported out of state.

Results

Characteristics of Identified Road Segments

Roadway sections having CMB installations at the time this study began were divided into 1,723 uniform road segments. For each uniform CMB segment, a matching uniform road segment of similar length without a CMB was identified by the process described in the Methods. This resulted in a total of 3,446 case and control road segments. Originally, the goal was to identify matching segments located near the cable segment, but with no median barrier of any kind. However, as the matching process progressed, it became apparent that was not feasible. As a result, many cable segments were matched with a similar segment having a median barrier of either concrete or metal guard rail.

Results of the matching process are presented in Table 2. There were 1,023 cable segments matched with a concrete segment; 571 cable segments matched with a segment having no median barrier; and 129 cable segments matched with a metal guardrail segment. The sample size of the cable-guardrail group was judged too small for reliable analysis; the cable-concrete and cable-no barrier groups were used for subsequent analyses.

Many of the identified uniform road segments had no police-reported crashes during the period studied, which was unanticipated in the original study design. Including both cable and control segments, there were 1,385 uniform road segments having at least one police-reported crash. These segments and crashes were included in the injury severity models — 550 of these segments had CMBs and 835 had other types of (or no) median barrier.

In the cable-concrete group, the cable segments tended to have fewer lanes (4 on average, vs. 6 for concrete); narrower medians (21 feet on average, vs. 26 feet for concrete); and longer offsets (23 on average, vs. 12 for concrete). All of the concrete barrier segments having at least one crash were located on interstates, whereas 8% of the CMB segments were located on state roads.

In the cable-no barrier group, the cable and no-barrier segments were more similar with respect to number of lanes and barrier offset, but mean median width was very different (14 feet for cable vs. 42 feet for no barrier). Whereas 90% of cable segments in this group were located on interstates, 27% of the no-barrier segments were located on parkways.

Counties

Cable segments were concentrated on major roadways near Jefferson County, northern Kentucky (Boone, Kenton, and Campbell Counties), and southeastern Kentucky (Laurel, Rockcastle, and Whitley Counties). Concrete segments were also located near Louisville and in northern Kentucky, but also with a higher concentration in central Kentucky (Fayette and Madison Counties).

Table 2 Characteristics of Identified Road Segments (N=2,068) By Type of Median Barrier

	Cable-Concrete		Cable-Metal		Cable-No barrier	
Characteristic	Cable	Concrete	Cable	Metal	Cable	No barrier
Number of uniform segments identified	1,023	1,023	129	129	571	571
Number of uniform segments on which at least 1 crash occurred (N = 1,385)	473	601	26	39	51	195
Number of lanes						
Mean	4.61	6.46	4.23	4.97	4.04	4.63
Median	4.00	6.00	4.00	4.00	4.00	4.00
Width of median						
Mean	20.97	25.82	19.42	32.32	14.25	41.68
Median	5.00	27.00	5.00	32.00	5.00	46.00
Barrier offset						
Mean	22.62	11.59	26.62	15.28	21.86	23.40
Median	12.00	12.00	12.00	12.00	12.00	25.00
Road type – N (%)						
Interstate	437 (92.4)	601 (100.0)	20 (76.9)	39 (100.0)	46 (90.2)	143 (73.3)
Parkway	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	52 (26.7)
State	36 (7.6)	0 (0.0)	6 (23.1)	0 (0.0)	5 (9.8)	0 (0.0)
Other	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
County – N (%)						
Boone	80 (16.9)	114 (19.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Campbell	28 (5.9)	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.0)	0 (0.0)
Christian	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	25 (12.8)
Fayette	0 (0.0)	134 (22.3)	0 (0.0)	3 (7.7)	0 (0.0)	9 (4.6)
Franklin	0 (0.0)	0 (0.0)	0 (0.0)	2 (5.1)	0 (0.0)	13 (6.7)
Hardin	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	21 (10.8)
Jefferson	134 (28.3)	86 (14.3)	14 (53.8)	14 (35.9)	15 (29.4)	8 (4.1)
Kenton	41 (8.7)	57 (9.5)	1 (3.9)	0 (0.0)	0 (0.0)	0 (0.0)
Laurel	50 (10.6)	42 (7.0)	3 (11.5)	0 (0.0)	5 (9.8)	2 (1.0)
Lyon	0 (0.0)	0 (0.0)	0 (0.0)	3 (7.7)	0 (0.0)	31 (15.9)
Madison	0 (0.0)	90 (15.0)	0 (0.0)	6 (15.4)	0 (0.0)	37 (19.0)
Marshall	0 (0.0)	0 (0.0)	0 (0.0)	3 (7.7)	0 (0.0)	17 (8.7)
Rockcastle	38 (8.0)	37 (6.1)	4 (15.4)	5 (12.8)	13 (25.5)	1 (0.5)
Whitley	102 (21.6)	0 (0.0)	4 (15.4)	0 (0.0)	17 (33.3)	0 (0.0)
Other	0 (0.0)	41 (6.8)	0 (0.0)	3 (7.7)	0 (0.0)	31 (15.9)

Characteristics of Crashes That Occurred on Identified Road Segments

There were 2,543 police-reported crashes on the 1,385 uniform road segments that had at least one crash — an average of 1.8 crashes per segment. On cable segments, crashes occurring in the study period but before the cable barrier installation date were excluded.

In the cable-concrete group, there were 583 crashes on 485 cable segments (1.2 crashes per segment) and 1,444 crashes on 601 concrete segments (2.4 crashes per segment). Crashes on cable segments in this group were more likely to be single vehicle crashes (67%) than were crashes on concrete segments (52.4%). Conversely, crashes on concrete segments were more likely to be angle crashes (32%) than were crashes on cable segments (18%). Crashes on concrete segments were more likely to involve a first event that occurred on the roadway and that involved another motor vehicle. Crashes on cable segments were more likely to involve an overturned vehicle (5% vs. 3% on concrete segments). Crashes on concrete segments were more likely to occur at higher posted speed limits and in wet road conditions (ice, snow, wet).

In the cable-no barrier group, there were 52 crashes on 51 cable segments and 353 crashes on 195 no-barrier segments. The manner of collision was similar on both types of segments. However, crashes on no-barrier segments were more likely to initiate in the median (30% vs 14% for cable) or on the roadway (34% vs. 17% for cable); and to involve another motor vehicle or a fixed object (presumably one located in the median — a tree, embankment, or rock cliff face). Significantly, crashes on no-barrier segments were 6 times more likely than crashes on matched cable segments to involve an overturned vehicle. Finally, 93% of crashes on no-barrier segments had a posted speed limit of 70 mph or 75 mph, compared to 48% for matched cable segments.

Table 3 Characteristics of Crashes (N=2,543) Occurring on Identified Road Segments on Which At Least One Crash Occurred

Characteristic	Cable-Concrete		Cable-Metal		Cable-No barrier	
	Cable	Concrete	Cable	Metal	Cable	No barrier
Number of crashes [a] (mean per segment)	588 (1.2)	1,444 (2.4)	39 (1.5)	67 (1.7)	52 (1.0)	353 (1.8)
Manner of collision						
Single vehicle	393 (66.8)	756 (52.4)	26 (66.7)	32 (47.8)	36 (69.2)	250 (70.8)
Angle	107 (18.2)	460 (31.9)	7 (18.0)	21 (31.3)	7 (13.5)	42 (11.9)
Head-on	45 (7.7)	126 (8.7)	3 (7.7)	7 (10.5)	3 (5.8)	28 (7.9)
Sideswipe	21 (3.6)	72 (5.0)	2 (5.1)	4 (6.0)	5 (9.6)	25 (7.1)
Other	22 (3.7)	30 (2.1)	1 (2.6)	3 (4.5)	1 (1.9)	8 (2.3)
Location of first event						
Outside shoulder – left	291 (49.5)	536 (37.1)	18 (46.2)	27 (40.3)	35 (67.3)	113 (32.0)
Roadway	144 (24.5)	597 (41.3)	11 (28.2)	31 (46.3)	9 (17.3)	120 (34.0)
Median	141 (24.0)	290 (20.1)	8 (20.5)	7 (10.5)	7 (13.5)	107 (30.3)
Other	12 (2.0)	21 (1.5)	2 (5.1)	2 (3.0)	1 (1.9)	13 (3.7)
First collision event						
Cable barrier	297 (50.4)	9 (0.6)	18 (46.1)	1 (1.5)	32 (61.5)	0 (0.0)
Concrete barrier	10 (1.7)	542 (37.5)	0 (0.0)	7 (10.5)	1 (1.9)	8 (2.3)
Motor vehicle	110 (18.7)	497 (34.4)	9 (23.1)	24 (35.8)	8 (15.4)	86 (24.3)
Median support	15 (2.6)	134 (9.3)	1 (2.6)	0 (0.0)	1 (1.9)	6 (1.7)
Fixed object	48 (8.2)	96 (6.7)	4 (10.3)	13 (19.4)	2 (3.9)	134 (38.0)
Other	108 (18.4)	166 (11.5)	7 (17.9)	22 (32.8)	8 (15.4)	119 (33.7)
Vehicle overturned						
Yes	30 (5.1)	43 (3.0)	1 (2.6)	9 (13.4)	2 (3.9)	83 (23.5)
No	558 (94.9)	1,401 (97.0)	38 (97.4)	58 (86.6)	50 (96.2)	270 (76.5)
Posted speed limit						
> 65 (70, 75)	179 (30.4)	786 (54.4)	18 (46.2)	41 (61.2)	25 (48.1)	328 (92.9)
55-65 (55, 65)	409 (69.6)	654 (45.3)	21 (53.8)	24 (35.8)	27 (51.9)	24 (6.8)
Other (35, 45)	0 (0.0)	4 (0.3)	0 (0.0)	2 (0.0)	0 (0.0)	1 (0.3)

Road condition						
Ice/snow/wet	203 (34.5)	787 (54.5)	15 (38.5)	28 (41.8)	21 (40.4)	163 (46.3)
Other	385 (65.5)	657 (45.5)	24 (61.5)	39 (58.2)	31 (59.6)	189 (53.7)

[a] For cable median barrier segments, crash counts include only crashes that occurred *after* the barrier was installed.

Characteristics of Occupants Involved in Crashes on Identified Road Segments

Compared to the crash characteristics, there were fewer noteworthy differences in occupant characteristics between the cable-concrete and cable-no barrier groups.

In the cable-concrete group, there were 1,034 occupants in the 583 reported crashes on cable segments (1.8 occupants per crash) and 2,946 occupants in the 1,444 crashes on concrete segments (2.0 occupants per crash). Significantly, drivers in crashes on cable segments were 2.3 times more likely to be impaired by drugs or alcohol than drivers in crashes on matching concrete segments. In terms of injury outcomes, occupants on concrete segments were 1.4 times more likely to have a police-reported injury than occupants on matching cable segments (10.6% to 7.5%). Conversely, occupants on cable segments were 1.35 times more likely to have an injury severity score (ISS) of 4 or higher, based on hospital-based physician injury diagnoses; and 2 times more likely to have an ISS of 8 or higher.

In the cable-no barrier group, there were 78 occupants in the 52 reported crashes on cable segments (1.5 occupants per crash) and 630 occupants in the 353 crashes on concrete segments (1.8 occupants per crash). Occupants on no-barrier segments were more likely to be aged 16 to 24 (30% vs. 22% on cable segments) and more than 4 times more likely to be unrestrained (5.6% vs. 1.3% on cable segments). In terms of injury outcomes, occupants on no-barrier segments were 3 times more likely to have a police-reported injury (20% vs. 6% on cable segments), and 2.5 times more likely to have an ISS of 4 or higher, based on hospital-based physician injury diagnoses.

Table 4 Characteristics of Occupants (N=4,900) Involved in Crashes on Identified Road Segments on Which At Least One Crash Occurred

Characteristic	Cable-Concrete		Cable-Metal		Cable-No barrier	
	Cable	Concrete	Cable	Metal	Cable	No barrier
Number of occupants	1,034	2,946	64	148	78	630
Age group						
16-24	270 (31.6)	731 (30.6)	17 (38.6)	41 (33.9)	14 (21.5)	155 (29.9)
25-34	228 (26.7)	607 (25.4)	13 (29.6)	22 (18.2)	19 (29.2)	136 (26.3)
35-44	147 (17.2)	413 (17.3)	7 (15.9)	15 (12.4)	16 (24.6)	73 (14.1)
45-54	122 (14.3)	376 (15.8)	5 (11.4)	24 (19.8)	10 (15.4)	88 (17.0)
55-64	87 (10.2)	260 (10.9)	2 (4.6)	19 (15.7)	6 (9.2)	66 (12.7)
65+	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Gender						
Male	556 (53.8)	1,629 (55.4)	36 (56.3)	69 (46.6)	45 (58.4)	346 (54.9)
Female	478 (46.2)	1,314 (44.7)	28 (43.8)	79 (53.4)	32 (41.6)	284 (45.1)
Person type						
Driver	721 (69.7)	1,906 (64.7)	46 (71.9)	93 (62.8)	57 (73.1)	419 (66.5)
Passenger	313 (30.3)	1,040 (35.3)	18 (28.1)	55 (37.2)	21 (26.9)	211 (33.5)
Driver impaired?						
Yes	55 (5.3)	69 (2.3)	1 (1.6)	11 (7.4)	5 (6.4)	31 (4.9)
No	979 (94.7)	2,877 (97.7)	63 (98.4)	137 (92.6)	73 (93.6)	599 (95.1)
Restrained?						
Yes	1,006 (97.3)	2,872 (97.5)	63 (98.4)	139 (93.9)	77 (98.7)	595 (94.4)
No	28 (2.7)	74 (2.5)	1 (1.6)	9 (6.1)	1 (1.3)	35 (5.6)
Ejected?						
Yes	6 (0.6)	7 (0.2)	1 (1.6)	1 (0.7)	0 (0.0)	8 (1.3)
No	1,028 (99.4)	2,936 (99.8)	63 (98.4)	145 (99.3)	77 (100.0)	622 (98.7)
Injury severity						
K/A/B[a]	77 (7.5%)	312 (10.6%)	3 (4.7%)	10 (6.8%)	5 (6.4%)	123 (19.5%)
ISS >= 4	31 (3.0%)	70 (2.4%)	2 (3.1%)	3 (2.0%)	1 (1.3%)	33 (5.2%)
ISS >= 8	20 (1.9%)	35 (1.2%)	1 (1.6%)	1 (0.7%)	0 (0.0%)	20 (3.2%)
MAIS >= 2	31 (3.0%)	70 (2.4%)	2 (3.1%)	3 (2.0%)	1 (1.3%)	33 (5.2%)
MAIS >= 3	15 (1.5%)	29 (1.0%)	1 (1.6%)	1 (0.7%)	0 (0.0%)	17 (2.7%)

[a] Killed, incapacitating injury, or non-incapacitating injury based on police accident report
[b] Injury Severity Score, based on physician-diagnosed injuries on the hospital record

[c] Overall Maximum Abbreviated Injury Score (most severe injury) based on physician-diagnosed injuries on the hospital record

Relationship Between Median Barrier Type and Injury Risk
This study's primary aim was to estimate the difference in the risk of occupant injury associated with the presence of a CMB compared to 1) no median barrier, and 2) a concrete median barrier. Table 5 presents approximate estimates of injury risk prior to adjusting for differences in vehicle and occupant characteristics that could bias the risk estimates.

Compared to road segments with no median barrier, occupants in median-involved crashes on a road segment with a CMB were 72% less likely to have a police-reported injury (statistically significant) and 76% less likely to have a physician-diagnosed ISS of 4 or greater (not statistically significant).

Relative to road segments with a concrete median barrier, results were conflicting. Occupants involved in crashes on a road segment with a CMB were 32% less likely to have a police-reported injury (statistically significant) but 27% *more* likely to have a physician-diagnosed ISS of 4 or greater, and 64% more likely to have a physician-diagnosed ISS of 8 or greater. This disparity persisted after controlling for possible confounding variables, as discussed below. The reasons for the disparity are not clear, as detailed in the Discussion section.

Table 5 Crude Estimates of Injury Risk on Cable Median Barrier Segments Compared to Concrete Median Barrier Segments and Segments with No Median Barrier

Median Barrier Comparison	**Injury Outcome Measure**[a]		
	K/A/B[b]	**ISS >= 4**[c]	**ISS >= 8**[c]
Cable vs. Concrete	0.68 (0.52, 0.88)*	1.27 (0.83, 1.95)	1.64 (0.94, 2.86)
Cable vs. No Barrier	0.28 (0.11, 0.71)*	0.24 (0.03, 1.74)	-- [d]

[a] Estimated odds ratio and 95% confidence limits
[b] Killed, incapacitating injury, or non-incapacitating injury based on police accident report
[c] Injury Severity Score, based on physician-diagnosed injuries on the hospital record
[d] Insufficient data to estimate: there were no occupants with ISS >= 8 on cable median barrier segments in the cable-no barrier data set
* Indicates a statistically significant difference in injury risk on cable median barrier segments, compared to reference

Cable median barrier vs. no median barrier
Table 6 presents the results from the GEE model of injury risk on cable median barrier segments vs. segments with no median barrier.

Relative to road segments with no median barrier, after controlling for occupant age, gender, restraint use, ejection, vehicle type, and rollover, occupants in median-involved crashes on a road segment with a CMB were 48% less likely to have a police-reported injury and 65% less likely to have a physician-diagnosed ISS of 4 or greater. However, neither of these results were statistically significant, likely as a result of the small numbers of occupants in the cable-no barrier group.

Table 6 Adjusted Estimates of Injury Risk on Cable Median Barrier Segments Compared to Segments with No Median Barrier

Risk Factor	Injury Outcome Measure[a]		
	K/A/B[b]	**ISS >= 4[c]**	**ISS >= 8[c]**
Cable Median Barrier (vs. No Barrier)	0.52 (0.20, 1.31)	0.35 (0.04, 3.02)	-- [d]
Age	1.01 (1.00, 1.02)	1.03 (1.01, 1.06)	-- [d]
Male (vs. Female)	0.66 (0.46, 0.95)	0.38 (0.15, 0.93)	-- [d]
Restrained (vs. Unrestrained)	0.28 (0.07, 1.09)	0.10 (0.03, 0.29)	-- [d]
Ejected (vs. Not Ejected)	2.1 (0.4, 11.0)	5.4 (0.7, 40.4)	-- [d]
Vehicle Rollover (vs. Not)	4.4 (2.6, 7.7)	2.1 (0.8, 5.3)	-- [d]
Passenger Car (vs. Light Truck)	1.2 (0.7, 2.0)	0.7 (0.3, 1.6)	-- [d]
Correlation[e]	0.829	0.069	0.088

[a] Estimated odds ratio and 95% confidence limits
[b] Killed, incapacitating injury, or non-incapacitating injury based on police accident report
[c] Injury Severity Score, based on physician-diagnosed injuries on the hospital record
[d] Insufficient data to estimate: there were no occupants with ISS >= 8 on cable median barrier segments in the cable-no barrier data set
[e] Estimate of correlation parameter within vehicle-level clustering
* Indicates a statistically significant difference in injury risk on cable median barrier segments, compared to reference

Cable Median Barrier vs. Concrete Median Barrier

Table 7 presents results from the GEE model. Relative to road segments with a concrete median barrier, after controlling for occupant age, gender, restraint use, ejection, vehicle type, and rollover, occupants in median-involved crashes on a road segment with a CMB were 42% less likely to have a police-reported injury (statistically significant).

However, when ISS was used as the injury outcome measure, the result was opposite: occupants in median-involved crashes on a road segment with a CMB were 4% more likely to have a physician-diagnosed ISS of 4 or greater, and 34% more likely to have a physician-diagnosed ISS of 8 or greater. Neither of these results were statistically significant, possibly due to the fact that there were 389 occupants in this group with a police-reported injury, but only 86 occupants with a hospital or ED record.

Table 7 Adjusted Estimates of Injury Risk on Cable Median Barrier Segments Compared to Segments with a Concrete Median Barrier

Risk Factor	Injury Outcome Measure[a]		
	K/A/B[b]	**ISS >= 4[c]**	**ISS >= 8[c]**
Cable Median Barrier (vs. Concrete)	0.58 (0.43, 0.78)*	1.04 (0.62, 1.72)	1.34 (0.67, 2.66)
Age	1.00 (1.00, 1.01)	1.02 (1.01, 1.03)	1.03 (1.01, 1.04)
Male (vs. Female)	0.69 (0.57, 0.84)	0.78 (0.54, 1.14)	0.81 (0.46, 1.40)
Restrained (vs. Unrestrained)	0.15 (0.09, 0.27)	0.15 (0.07, 0.33)	0.08 (0.03, 0.20)
Ejected (vs. Not Ejected)	18.6 (0.9, 379.4)	9.1 (2.5, 32.7)	11.9 (2.8, 50.6)
Vehicle Rollover (vs. Not)	8.1 (4.9, 13.6)	7.0 (3.7, 13.2)	10.3 (4.8, 22.0)
Passenger Car (vs. Light Truck)	1.48 (1.14, 1.93)	1.38 (0.86, 2.20)	0.91 (0.49, 1.70)
Correlation[d]	0.393	0.211	0.160

[a] Estimated odds ratio and 95% confidence limits
[b] Killed, incapacitating injury, or non-incapacitating injury based on police accident report
[c] Injury Severity Score, based on physician-diagnosed injuries on the hospital record
[d] Estimate of correlation parameter within vehicle-level clustering
* Indicates a statistically significant difference in injury risk on cable median barrier segments, compared to reference

Discussion

We investigated whether injury risk in median-involved traffic crashes on road segments with CMBs differs from road segments with concrete median barrier or no median barrier. After controlling for occupant and vehicle factors that could influence injury severity, as well as the nesting of occupants within vehicles, we found that the odds of a police-reported injury were 42% lower on road segments with a CMB than on road segments with a concrete median barrier; this difference was statistically significant. Conversely, using physician injury data, we found the odds of an ISS >=8 were 34% higher on CMB segments than on concrete median barrier segments. However, this result was not statistically significant.

Moreover, models suggested that odds of both police-reported and hospital-reported injury were lower (by 48% and 65%, respectively) in median-involved crashes on road segments with CMBs than on segments with no median barrier. Neither difference was statistically significant.

The number of crashes in our sample was smaller than anticipated due to limited miles of installed CMBs. This is likely the primary reason for the wide confidence intervals around estimated odds ratios for injury on CMB road segments, and therefore the lack of statistical significance. The small sample size also ruled out analysis of specific injury types (e.g., traumatic brain injury or spinal cord injury), as they are relatively uncommon to begin with.

The finding of a higher likelihood of more severe, physician-diagnosed injury (ISS >=4 and ISS >=8) on CMB segments vs. concrete — although not statistically significant — was unexpected (see Table 6). It raises questions which require further study before drawing any firm conclusions. If we arrive at different answers to the main research question depending on whether we use the police-reported KABCO injury scale or physician diagnosis-based ISS, this has important implications for traffic safety research.

Context

A 2009 article reviewed CMB use and its effectiveness in 23 states, having more than 4,183km of installed barriers as of 2007 (Ray et al. 2009). The authors pointed to previous research in several states (AL, AZ, MO, NC, OH, OK, OR, TX, UT, FL, NC, WA) demonstrating that CMBs were highly effective in both fatal and nonfatal median crossover crashes.

A 2011 study of motorcycle crashes reported no statistically significant difference in the odds of severe injury (killed or incapacitating injury on the KABCO scale) in collisions with a CMB relative to collisions with a W-beam guardrail. The number of motorcycle collisions with CMBs was low — 46 crashes over a six-year period.

A 2014 article analyzed single-vehicle crashes in Indiana using data from Indiana DOT's electronic longitudinal barrier inventory. It reported that hitting a near-side CMB (offset between 10 ft. and 29 ft.) was associated with an 85% lower risk of police-reported injury (i.e., killed, incapacitating injury, or non-incapacitating injury on the KABCO scale) compared to a high-risk

collision event in the absence of a barrier (striking a hazardous object or rolling over). Also, hitting a far-side CMB (>= 30ft offset) was associated with 78% lower odds of injury compared to a high-risk collision event. These results agree with our findings on CMB vs. no median barrier, though our effect sizes were smaller (48% using police-reported injury, 65% using ISS).
Moreover, the odds of injury when striking a CMB were lower than the odds when striking a guardrail face (57% lower for near-side barrier, 37% lower for far-side barrier). Cable and concrete median barriers were not compared.

Lessons Learned
We revised the original study design based on findings during the process of identifying matched segments for the cable barrier segments, and during the process of matching crashes to the identified road segments. Following is a summary of key lessons learned, which might be used to avoid comparable issues arising during future studies.

Sample Size
Sample size was smaller than we had anticipated, which limited what we could do with hospital-based injury data. Kentucky has a limited number of miles of installed CMBs, which implies a smaller-than-anticipated number of occupants (in crashes on CMB road segments), who received treatment at a hospital or emergency department. Future integration projects involving roadway and injury data should take this into account at the study design stage.

Matching Process for Road Segments
The original design called for matching each identified, uniform CMB segment with a similar road segment that had no median barrier. There proved to be too few miles of comparable road with no median barrier to accomplish this objective. Most cable segments, in the end, were matched with segments having a concrete median barrier. Some exploratory analysis of roadway characteristics is advisable as part of the study design process.

Possible Record Linkage Bias Due to Out-of-State Transports
The unexpected finding of occupants having greater odds of ISS>=4 and ISS>=8 injuries in crashes on CMBs, compared to concrete median barrier segments, led us to the following hypothesis. One explanation for this finding is that occupants involved in crashes on concrete segments were more likely to be transported to an out-of-state trauma center for medical treatment. Hospital records for occupants treated out of state were not available to us for linkage. If this hypothesis were true, some seriously injured occupants would have been incorrectly classified as uninjured; this would have been more common for occupants involved in crashes on concrete segments compared to cable segments.

Out-of-state transport is more likely in certain parts of the state that are closer to a Level I Trauma Center in another state, such Vanderbilt University Medical Center in Nashville, University of Tennessee Medical Center in Knoxville, University Hospital in Cincinnati, or Cabell-Huntington Hospital in West Virginia. To investigate, we produced a map of all identified road segments with cable, concrete, or no median barriers (Figure 2). At first glance, this map appears to suggest the opposite: there are more miles of CMBs in areas where occupants could be expected to be transported to Nashville or Knoxville for medical treatment.

Next, we reviewed CRASH narratives for all 77 occupants involved in crashes on CMB segments and all 312 occupants involved in crashes on concrete barrier segments, looking for evidence of transport out of state for medical treatment. We found the proportions to be roughly similar: 4 out of 77 occupants involved in crashes on cable segments were transported out of state (5.2%), while 14 out of 312 occupants involved in crashes on concrete segments were taken to an out-of-state facility (4.5%). In summary, we found no evidence of a difference in the frequency of out-of-state transport by median barrier type. As a result, there is no reason to suspect an out-of-state transport bias as explanation for increased injury risk on cable segments when using ISS as the injury outcome measure.

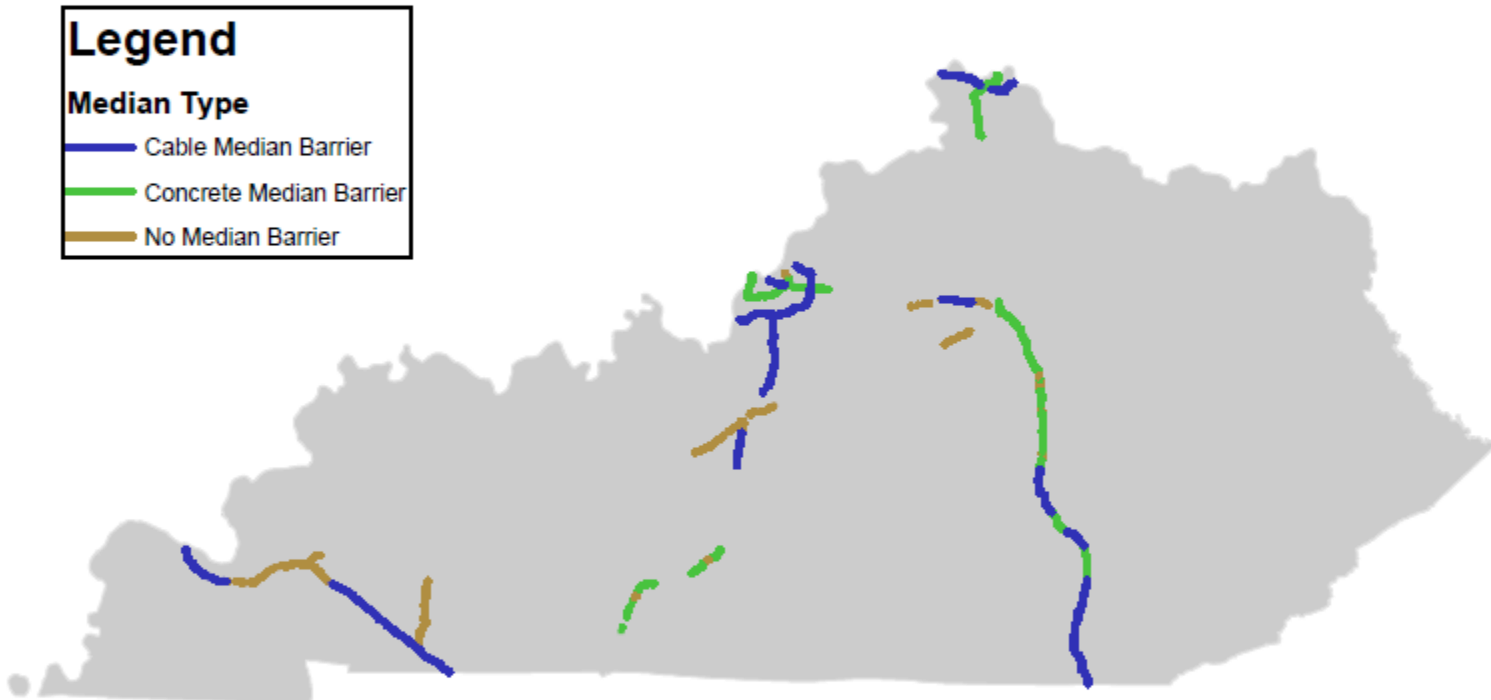

Figure 2 Locations of Identified Road Segments by Type of Median Barrier

Conclusion

Our findings suggest that conclusions arrived at based on physician-based injury severity measures may in some cases differ from conclusions reached based on police-reported injury severity measures. However, a number of limitations of the present study have been noted. The issue of differences in police- vs. physician-reported injury severity measures bears further investigation using approaches that address the lessons learned from this pilot study.

It is important to restate that this study did not address the question of crash prevention, only the risk of injury in crashes that occurred and were reported by police.

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