Testing Transit Bus Automated Collision Avoidance Warning Systems in Revenue Operations – Active Safety Collision Warning Pilot in Washington State

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Rosco/Mobileye Shield+ system
collision avoidance warning system (CAWS)
specifically designed for transit buses

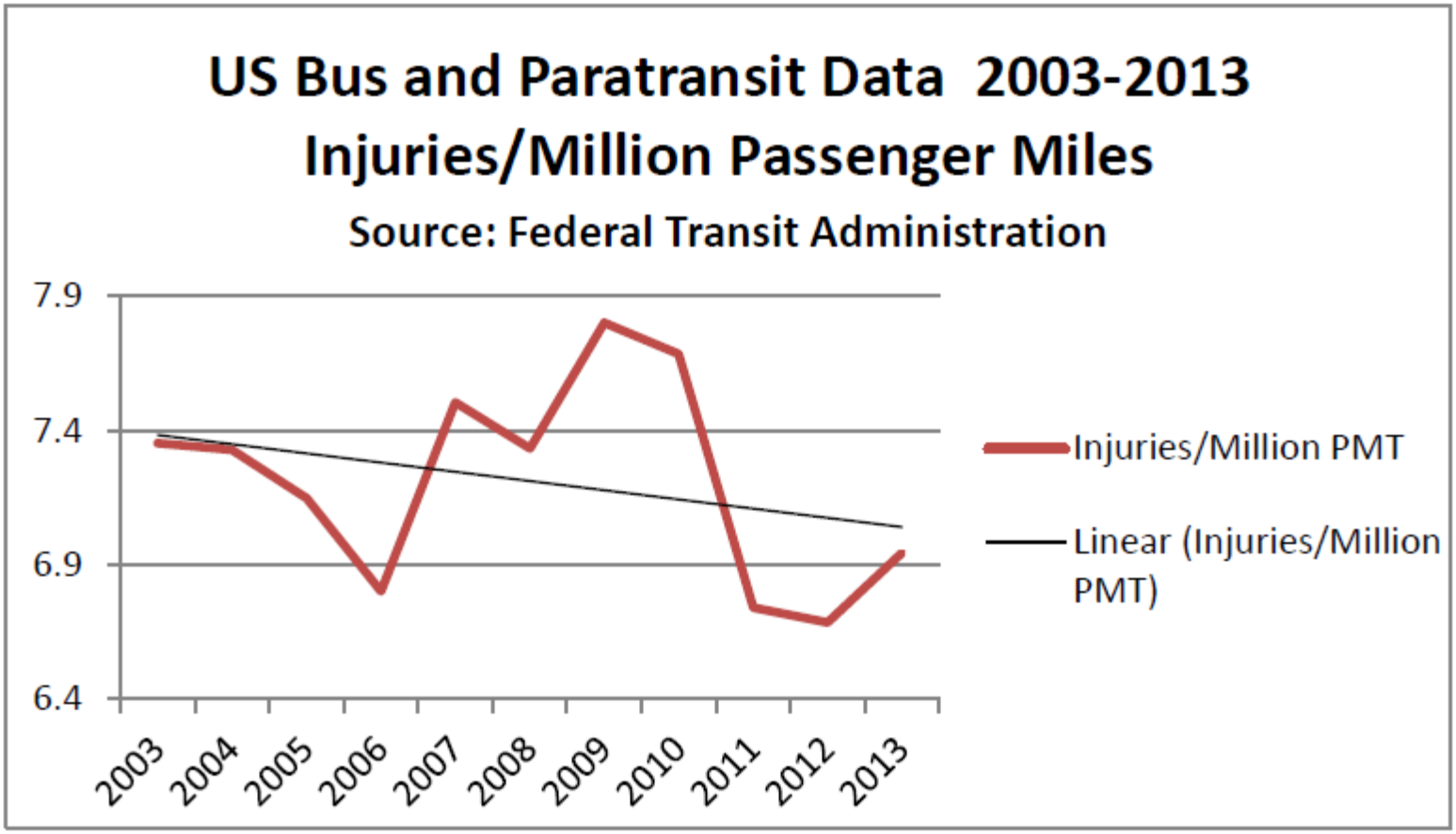
Provides alerts and warnings for events that could lead to a collision:

- changing lanes without activating a turn signal
- exceeding posted speed limit
- closing with vehicle in front of the bus
- closing with pedestrian or bicyclist in front of, or alongside the bus

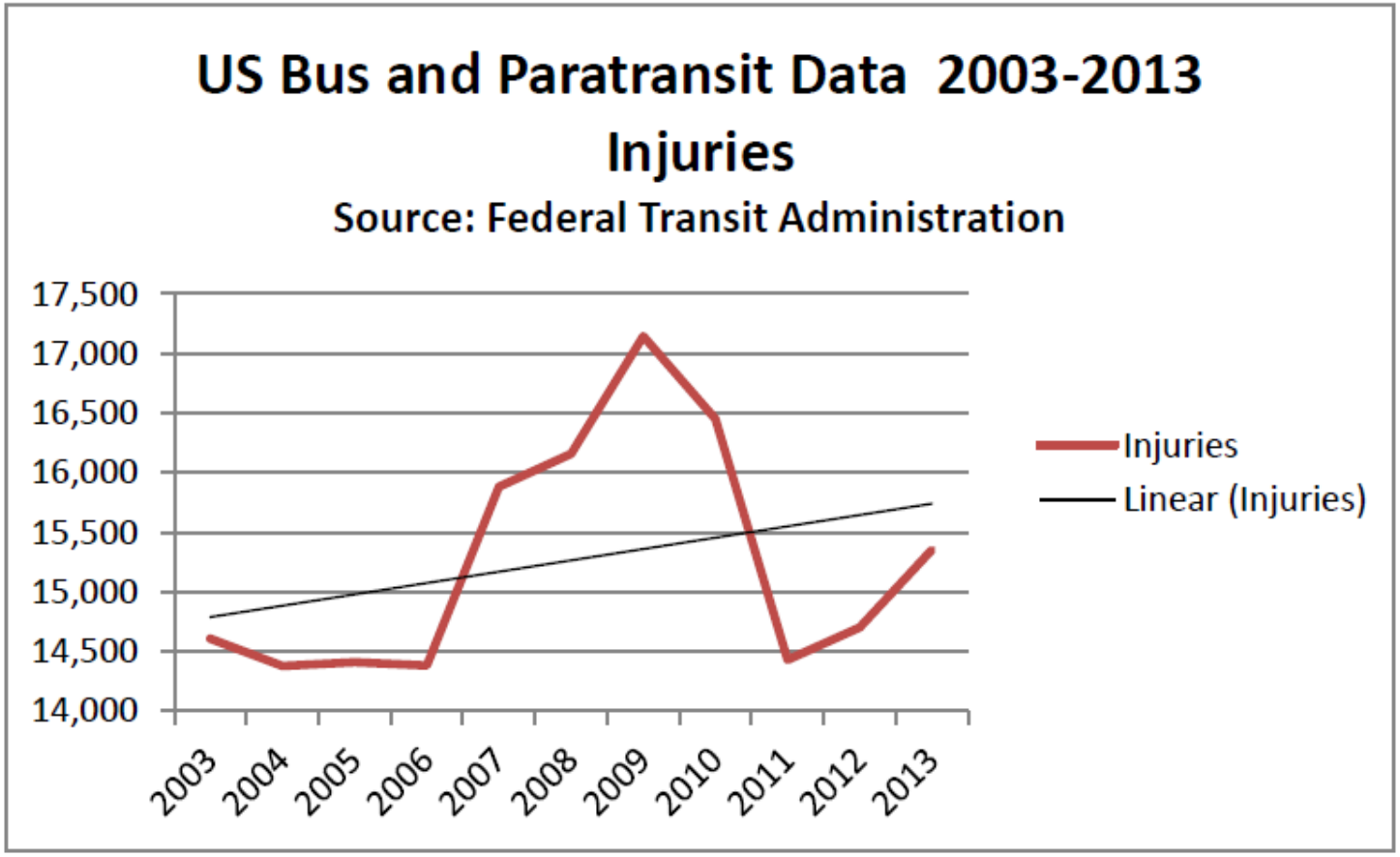
Alerts and warnings

- visual indicators on windshield and front pillars
- Audible warnings issued when collisions are imminent

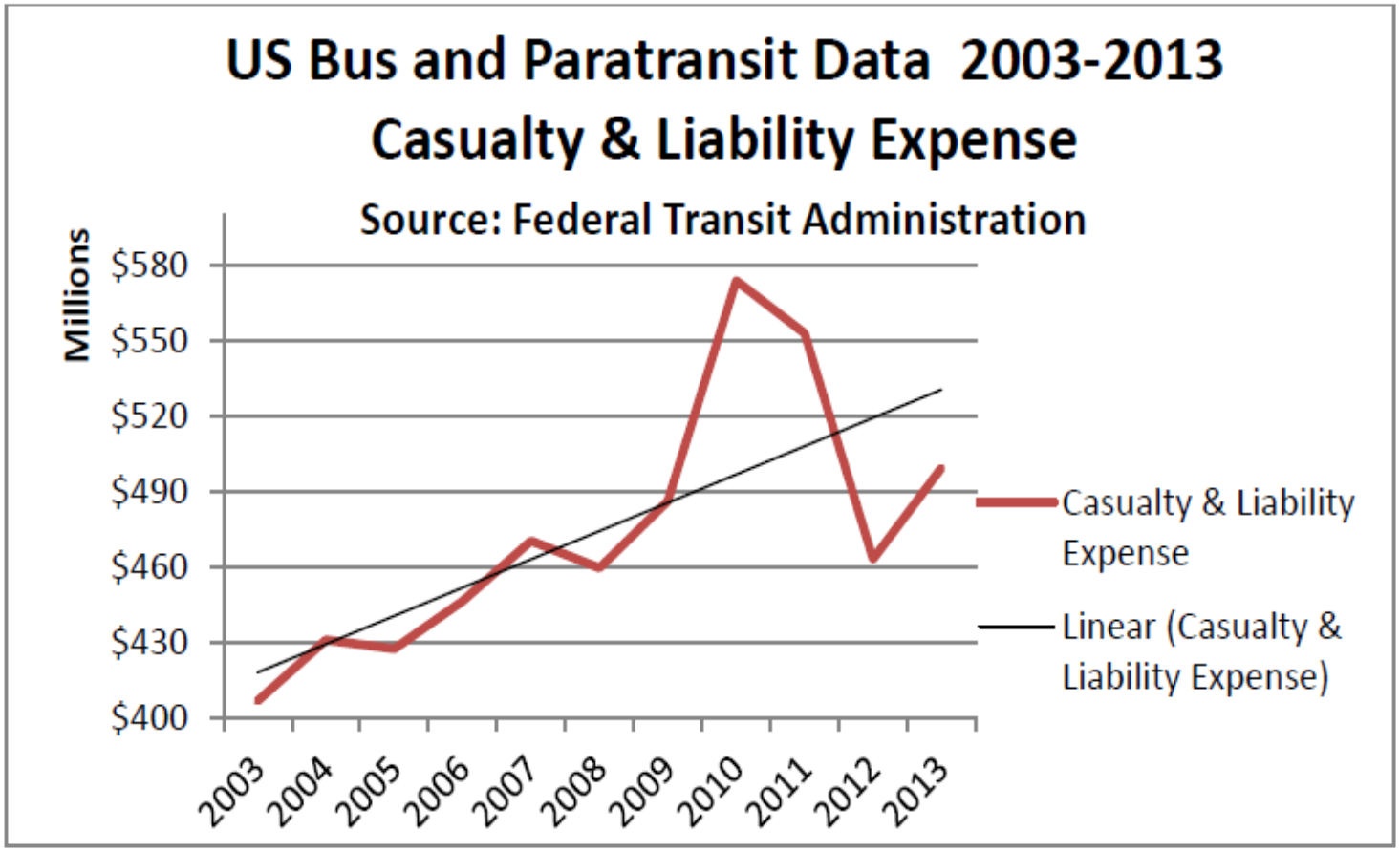
Trend in Rate of Bus and Paratransit Injuries per Passenger Mile



Trend in Number of Bus and Paratransit Injuries per Year



Trend in Bus and Paratransit Casualty and Liability Expenses



Collisions, Fatalities, Injuries, Casualty and Liability Expenses for Bus and Rail Modes

Mode	Reporting Period 2002-2014			Reporting Period 2002-2013
	Collisions	Fatalities	Injuries	Total Casualty and Liability Expenses by Mode
Total Bus, Demand Responsive and Van Pool	85,391	1,340	201,382	$5.75 Billion
Total Rail	6,118	1,303	89,806	$3.17 Billion

National Transportation Safety Board (NTSB)

2015 - Special Investigation Report – The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear End Crashes

- "currently available forward collision avoidance technologies for passenger and commercial vehicles … could reduce rear-end crash fatalities."

- Forward collisions reduced 71% for trucks with collision avoidance systems, (CAS) autonomous emergency braking, (AEB) and electronic stability control (ESC)

NTSB recommendations:

- Manufacturers - install forward collision avoidance systems on all newly manufactured passenger and commercial motor vehicles
- NHTSA - expand New Car Assessment Program to include graded performance rating of forward collision avoidance systems
- NHTSA - expand or develop protocols for assessment of forward collision avoidance systems

Transit May Be Left Behind

- Transit buses are a niche market – little incentive for OEM's to invest in R&D
- Agencies required to retain buses for 12 + years
- Years before transit benefits from CAS and AEB on new buses
- Need to retrofit existing buses with CAS and AEB
- Need standards for CAS and AEB for retrofits and new buses

Innovations Deserving Exploratory Analysis (IDEA)

TRB grant and funding from insurance companies

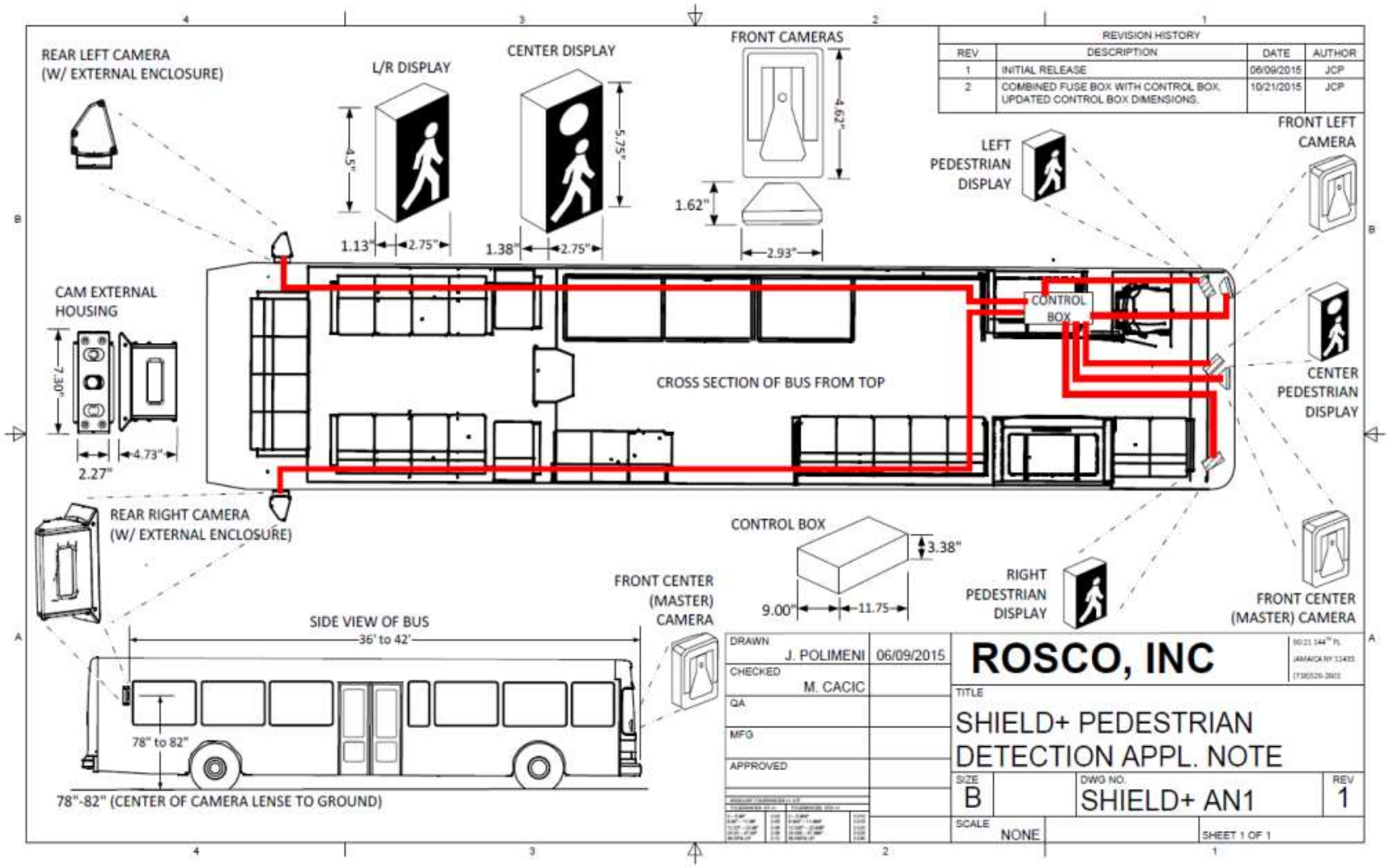
- Equipped 35 transit buses at seven member agencies and three buses at King County Metro with CAS
- Comprehensive examination of total costs for most severe and costly types of collisions
- Evaluate potential for CAS to reduce the frequency and severity of collisions, and reduce casualty and liability expenses
- Does not include autonomous braking in this phase

Shield+ system being installed on Gillig bus at C-TRAN in Vancouver, WA

- 6 different types of transit buses produced by three mfrs.
- high floor, low floor, Diesel, hybrid, and electric trolley buses
- 2-person team complete one bus installation in 8 hour period

Center indicator illuminates as pedestrian crosses in front of moving bus during testing

System Configuration



System Configuration - Alerts and Warning Displays

"MOBILEYE SHIELD+" OPERATOR REFERENCE GUIDE

MOBILEYE
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ROSCO VISION SYSTEMS
OFFICIAL MOBILEYE PARTNER

LEFT SIDE DISPLAY

OFF

- Left Side Pedestrian Display
- For detecting pedestrians and cyclists who are near left front corner of bus or left side of bus.

DETECTION

- Yellow illumination with no sound
- Informs the operator a pedestrian or cyclist has been detected near the left front or left side of bus.
- Operator should exercise additional caution until verifying that the danger of collision has passed.

ALERT

- Red flashing with beeping sound
- Informs the operator a pedestrian or cyclist has been detected in the left front or left side of bus and collision is imminent.
- Operator should take action to carefully stop bus to avoid collision.

CENTER DISPLAY & EYEWATCH

OFF

- Center Display
- Contains the Pedestrian Display and EyeWatch.
- The EyeWatch readouts and explanations can be found below on this document.

DETECTION

- Yellow illumination with no sound
- Indicates a pedestrian or cyclist is in front of the moving bus or coming towards the moving bus.
- Operator should exercise additional caution until verifying that the danger of collision has passed.

ALERT

- Red flashing with beeping sound
- Indicates a pedestrian or cyclist is in front of the moving bus or coming towards the moving bus and collision is imminent.
- Operator should take action to carefully stop bus to avoid collision.

RIGHT SIDE DISPLAY

OFF

- Right Side Pedestrian Display
- For detecting pedestrians and cyclists who are near right side of bus.

DETECTION

- Yellow illumination with no sound
- Informs the operator a pedestrian or cyclist has been detected near the right side of bus.
- Operator should exercise additional caution until verifying that the danger of collision has passed.

ALERT

- Red flash with beeping sound
- Informs the operator a pedestrian or cyclist has been detected on the right side of bus and collision is imminent.
- Operator should take action to carefully stop bus to avoid collision.

EYEWATCH READOUTS

							
• Solid green dot with hash marks on each side. • System is operational with bus at 0 speed.	• Solid green dot • System is operational.	• Lane Departure Warning (LDW) • Occurs when crossing the lane markers without using turn signal. • Appears as a vertical white hash line on the Eyewatch • A series of sharp warning beeps of short duration. • The hash line will be on the Eyewatch side corresponding to the lane marker crossed. • For pilots this feature is not active	• Speed Limit Indicator (SLI) • Appears when the bus is traveling at least 5 mph (adjustable) over the last posted speed limit sign. • Two vertical white hash lines on each side of the Eyewatch will appear with a white number indicating miles over the last posted speed limit • Has a chime sound. • Operator should reduce speed to keep within the speed limit.	• Headway Monitoring (HMW) • Appears as green car • Indicates detection of a vehicle in the path of the bus. • No number shown if bus is traveling a safe distance behind the vehicle in front or when bus is traveling below 19 MPH.	• Headway Monitoring (HMW) • Appears as green car and number • Indicates how far the vehicle in front of the bus is in seconds. • The 2.5 indicates the seconds until a collision could occur if the front vehicle were to come to a stop. • Operator is advised to reduce speed if time to collision falls below preset seconds and car turns red. • Has a chime sound.	• Headway Monitoring Warning (HMW) • Appears as a red car with an audible chime • Indicates the distance between bus and vehicle in front has fallen below a safe threshold. • Operator is advised to reduce speed to increase distance to a safe level.	• Forward Collision Warning (FCW) • Appears as flashing red car with a high pitched beeping sound • Indicates rear end collision is imminent • Operator must stop the bus immediately

T: 718.526.2601

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System Configuration - Alerts and Warning Displays

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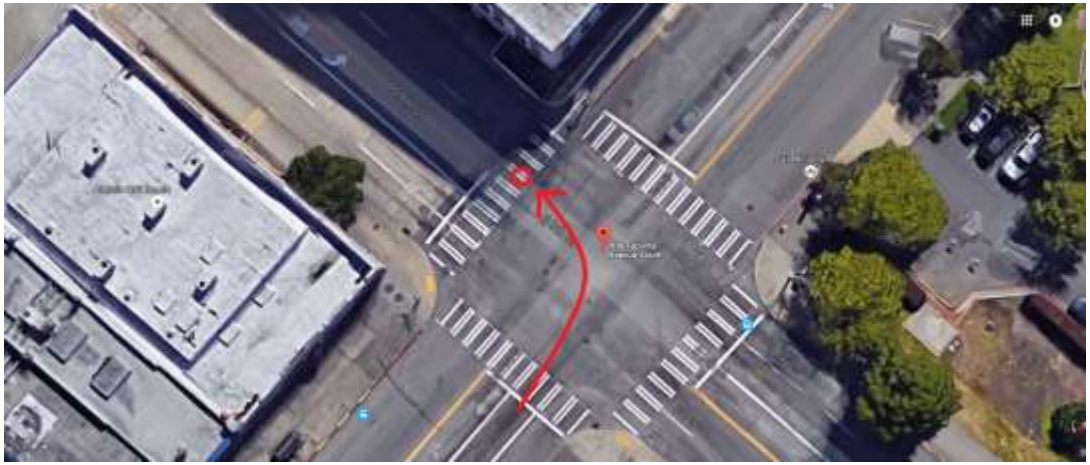
Telematics - Monitoring System Performance

- The CAS does not record video
- Additional cameras record video of events
- Additional technology is used to generate data that can be used to evaluate the systems' effectiveness
- Telematics unit captures and transmits data

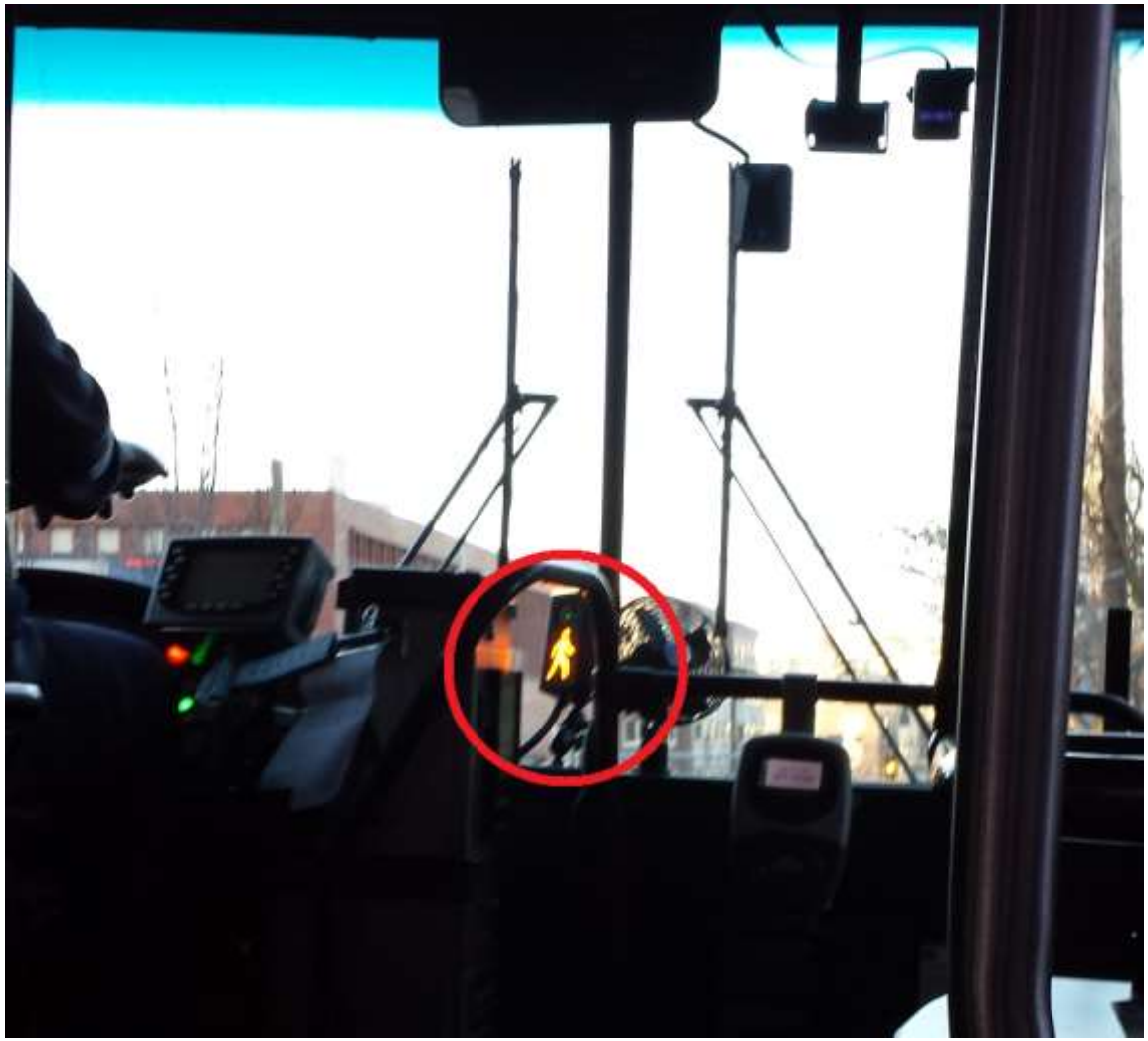
Monitoring System Performance with Telematics and Video

Field Testing the CAS-Mapping Telematics Data



Field Testing the CAS

Checking System Performance in Revenue Service –
comparing real time observations with telematics data



Field Testing the CAS- Logging Telematics Data

8	**Number of selected vehicles** : 1 Information exists for 1 of 1 vehicles selected									
9	**Time Period:** : 28/03/2016 21:20:00 - 28/03/2016 22:20:59									
10	**Total Records** : 44									
11	Report Name : -	Vehicle name	Heading	Distance In Miles	Driver name	Address	Speed	Status Name	Rule name	POI Original
	28/03/2016 21:57:25	KCM #4346	NE	3.29		1333-1367 Madison St, Seattle, WA 98104, USA	14	ME - Pedestrian In Range Warning	ME4 - Pedestrian In Range Warnin	
15										
16	28/03/2016 21:57:29	KCM #4346	NE	3.29		1368-1398 Madison St, Seattle, WA 98104, USA	14	PDZ-R	ME4 - PDZ - Right	
	28/03/2016 22:00:06	KCM #4346	NE	3.73		1349-1397 E Madison St, Seattle, WA 98122, USA	14	ME - Pedestrian In Range Warning	ME4 - Pedestrian In Range Warnin	
17										
18	28/03/2016 22:00:07	KCM #4346	NE	3.73		1349-1397 E Madison St, Seattle, WA 98122, USA	12	ME-PCW		
	28/03/2016	KCM #4346	NE	3.73		1350-1398 E Madison St	11	ME -	ME4 -	

WASHINGTON STATE PILOT PARTICIPANTS DATA ANALYSIS

	SHIELD+ SYSTEM ALERTS	Spokane Transit	Everett Transit	community transit	C-TRAN	INTERcity TRANSIT	Kitsap Transit	King County METRO	PIERCE TRANSIT
APRIL	Exceeded Speed Limits	19.18	20.20 5%	16.55 -14%	19.19 0%	11.11 -42%	16.46 -14%	6.41 -67%	13.69 -29%
	HMW (Headway Monitoring)	386.27	62.77 -84%	39.33 -90%	75.88 -80%	45.49 -88%	45.06 -88%	26.96 -93%	48.67 -87%
	UFCW (Urban Forward Collision Warning; speed 0 to 19 mph)	314.19	38.32 -88%	85.39 -73%	81.14 -74%	87.30 -72%	162.07 -48%	543.54 73%	126.62 -60%
	FCW (Forward Collison Warning; speed > 19 mph)	7.85	3.91 -50%	6.89 -12%	4.52 -42%	4.24 -46%	13.75 75%	6.76 -14%	4.95 -37%
	PCW Per 1k Miles	20.10	12.54 -38%	22.55 12%	3.31 -84%	31.06 55%	38.63 92%	63.79 217%	11.91 -41%
	PDZs Per 1k Miles	1275.26	569.87 -55%	849.72 -33%	523.32 -59%	1009.43 -21%	1535.27 20%	3881.49 204%	717.74 -44%
MAY	Exceeded Speed Limits	9.57	34.69 263%	17.95 88%	26.52 177%	9.16 -4%	13.47 41%	8.20 -14%	14.97 56%
	HMW (Headway Monitoring)	156.95	73.66 -53%	49.24 -69%	74.74 -52%	31.27 -80%	36.83 -77%	12.83 -92%	54.35 -65%
	UFCW (Urban Forward Collision Warning; speed 0 to 19 mph)	201.90	102.86 -49%	99.11 -51%	86.83 -57%	81.15 -60%	129.19 -36%	521.00 158%	133.97 -34%
	FCW (Forward Collison Warning; speed > 19 mph)	7.41	12.17 64%	10.06 36%	8.41 14%	3.25 -56%	12.23 65%	2.57 -65%	5.29 -29%
	PCW Per 1k Miles	28.08	13.30 -53%	22.25 -21%	3.38 -88%	25.08 -11%	29.39 5%	69.77 148%	15.06 -46%
	PDZs Per 1k Miles	1505.78	669.7 -56%	968.8 -36%	496.5 -67%	850.76 -44%	1003.52 -33%	4016.61 167%	751.41 -50%
JUNE	Exceeded Speed Limits	16.82	19.51 16%	22.81 36%	27.97 66%	8.91 -47%	14.16 -16%	3.00 -82%	18.69 11%
	HMW (Headway Monitoring)	66.35	86.03 30%	44.09 -34%	66.02 0%	43.84 -34%	47.17 -29%	26.10 -61%	53.79 -19%
	UFCW (Urban Forward Collision Warning; speed 0 to 19 mph)	354.18	44.63 -87%	94.15 -73%	68.78 -81%	102.77 -71%	143.23 -60%	551.14 56%	141.56 -60%
	FCW (Forward Collison Warning; speed > 19 mph)	14.33	9.43 -34%	7.25 -49%	6.49 -55%	5.34 -63%	15.98 12%	6.80 -53%	4.47 -69%
	PCW Per 1k Miles	31.10	10.39 -67%	24.84 -20%	4.18 -87%	30.60 -2%	36.49 17%	71.61 130%	11.99 -61%
	PDZs Per 1k Miles	1382.02	452.6 -67%	854.6 -38%	375.1 -73%	932.95 -32%	1103.60 -20%	3892.09 182%	733.20 -47%

- All data per 1K miles
- All data shown as monthly averages
- % Difference calculated from Spokane monthly average vs. respective transit monthly average
- % Removed data outliers from BenFrank on Exceeded Speed Limits

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Comparing Frequency of Alerts and Warnings with Spokane Transit Control Group

	SHIELD+ SYSTEM ALERTS	Spokane Transit		community transit		C-TRAN		INTERcity TRANSIT	
APRIL	Exceeded Speed Limits	19.18	20.20 5%	16.55 -14%		19.19 0%		11.11 -42%	
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	PDZs Per 1k Miles	1275.26	569.87 -55%	849.72 -33%		523.32 -59%		1009.43 -21%	

Data Collection
April 1, 2016 – June 30, 2016

- 352,129 operating miles
- 23,798 operating hours
- 250 driver surveys returned
- 178 comments received
- 16,600 hours of video
- 10,000 events logged
- 19 TB of video storage

Video Analyses by UW
Testing for False Positives and False Negatives

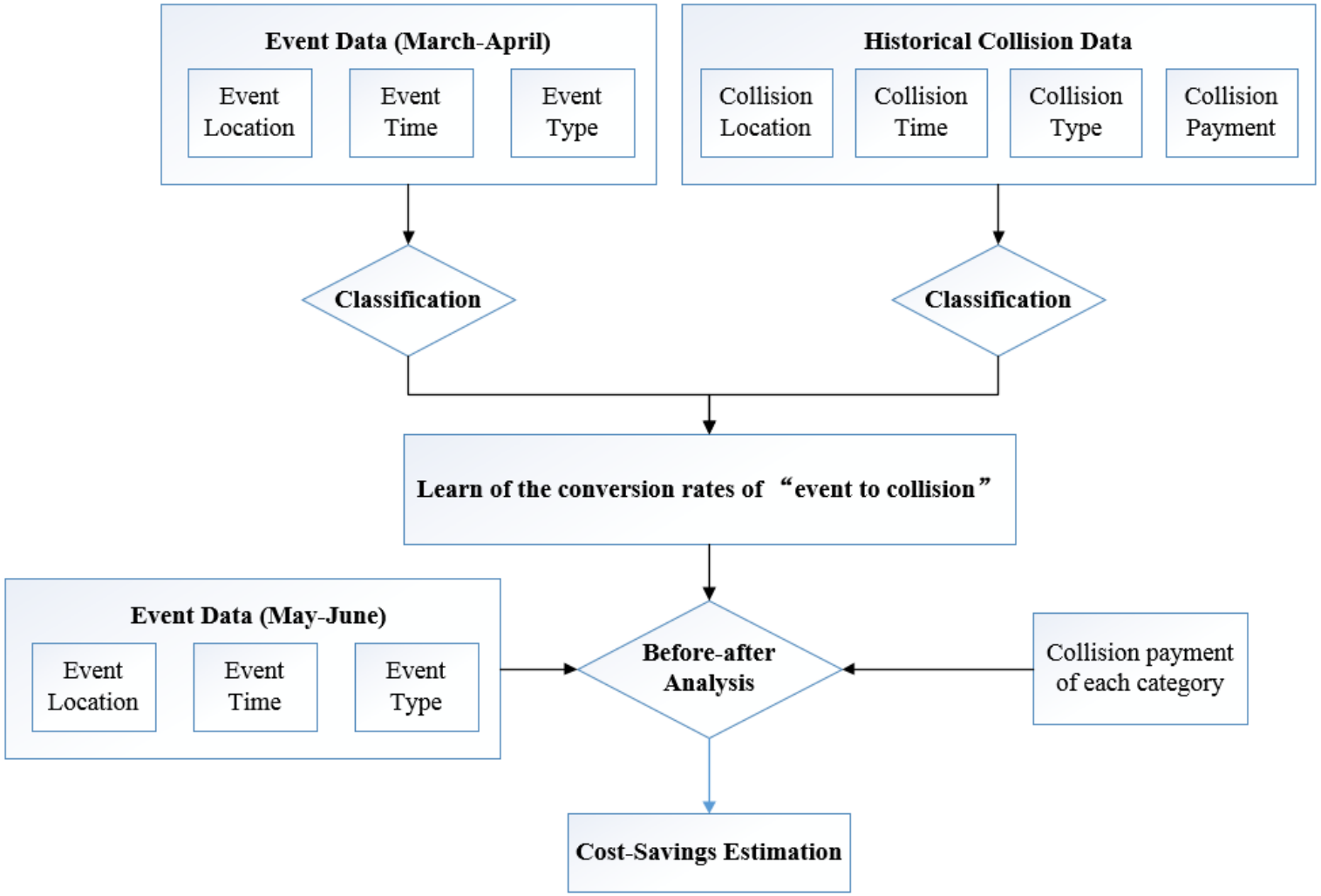
(a)

(b)

(c)

(d)

Framework for Estimating Cost Savings



Insurance Pool Data - Major Portion of Injuries, Fatalities, and Claims are Collision Related

Examination of 232 closed claims for Washington State Transit Insurance Pool spanning 2006-2015

- 100% of fatalities (6 total) were collision-related (vehicle, pedestrian, and bicyclist)
- 88% of injuries (335 total) resulted from collisions or sudden stops
- 94% of claims ($24.9 million total) resulted from collisions or sudden stops

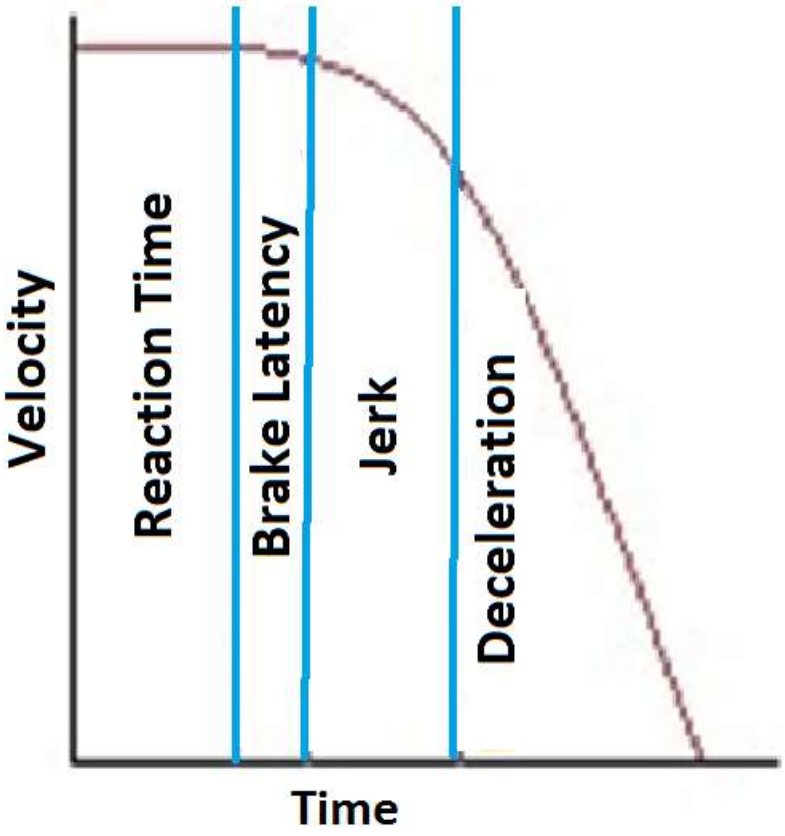
MANY OF THESE COULD HAVE BEEN PREVENTED WITH CAS AND AEB

Research Implications – The Business Case for CAS/AEB

Bus Type	2015 Casualty & Liability Expense per Bus
Commuter Bus	$6,229
Motor Bus	$7,986
Rapid Bus (BRT)	$4,116
Trolley Bus	$11,796

What Next - Autonomous Braking

- **The curved line shows velocity of the bus when braking**



The Need for Standards and Specifications

Transit buses require different CAS-AEB technology than cars and trucks

- Blind spot locations are different
- Operator training and workload
- Proximity of pedestrians and waiting passengers
- Standing passengers could be injured from sudden stops
- Buses in service 12 -18+ years - ability to retrofit is key
- Can not take buses out of service for long periods – standards help design systems for quicker retrofits and maintenance
- Most buses purchased through competitive bidding requiring detailed specifications for CAS-AEB

Thank You

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