Reading the Road Ahead: The Automated Vehicles Symposium's Machine Vision Research Perspective on Infrastructure Readiness

Scott O. Kuznicki, P.E.

International Symposium on Traffic Signs & Pavement Markings
Zagreb, Croatia | Oct 3-4, 2019

DISCOVERY INSTITUTE

The Transportation Futures Research Fellowship
Cascadia Center for Regional Development

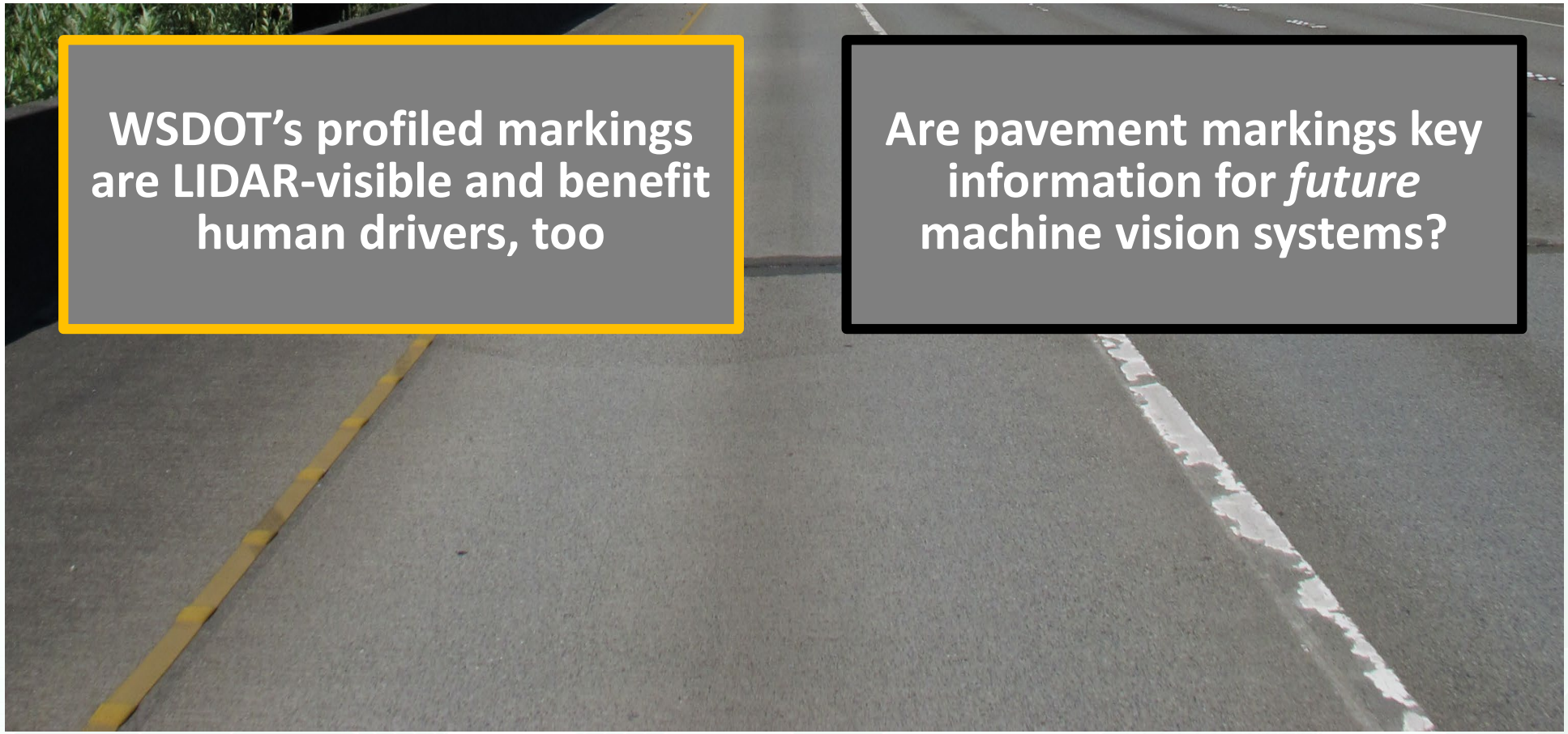
HAVE WE GONE BANANAS?

DISCLAIMER

THE ROLE OF INTUITION


GOLF
TR·3366 R
DAF
BEV

DRIVING QUESTION . . .



WSDOT's profiled markings are LIDAR-visible and benefit human drivers, too

Are pavement markings key information for *future* machine vision systems?

CHALLENGES

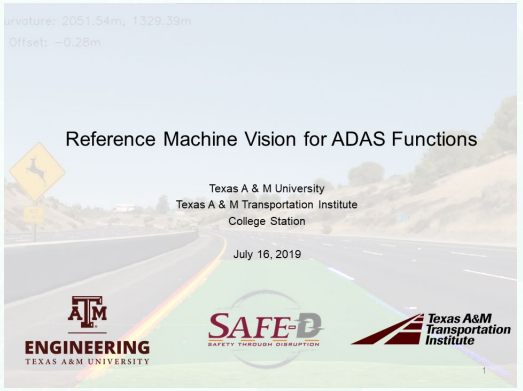
- Wide variety of use cases
- Safety challenges are incongruent with operating design domains of least complexity
- Inconsistent application of standards
- Wide variation in marking visibility, often due to weather effects and varying maintenance

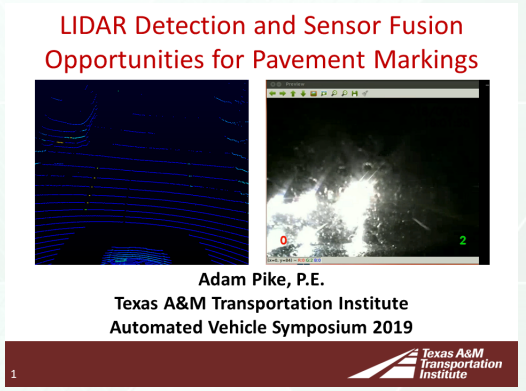
AVS 2019

"Reading the Road Ahead"

- Machine vision and traffic control device interactions
- Emphasis on understanding failure modes
- 2019: Preparing Infrastructure for ADAS and HAV
- Moving ahead with co-organizer Ken Smith from 3M
- Thank you to TRB and AUVSI

INDUSTRY EXPERTISE





INDUSTRY EXPERTISE

Scott O. Kuznicki

Modern Traffic Consultants

INDUSTRY EXPERTISE

AUTOMATED VEHICLES SYMPOSIUM 2019
USERS. VEHICLES. INFRASTRUCTURE.

SESSION 16

THE MYTH OF
UNIDIMENSIONAL AUTOMATION

Human-Centric Automation

- **Capabilities**
- **Limitations**
- **Ability to Adapt?**
- **Ability to Learn?**
- **Intuition?**

AVS 2019 - Session 16 [modern traffic consultants] 9

WSDOT

"Achieve superior competence in your strategic areas of focus and obtain confidence from manufacturers for deployment here in Washington State."

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INDUSTRY EXPERTISE

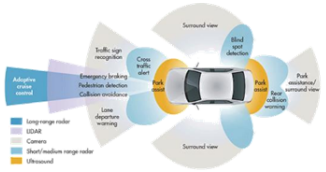
Ken Smith

3M

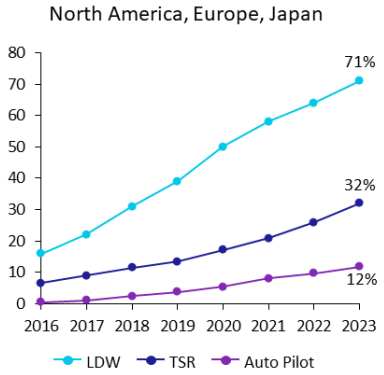
INDUSTRY EXPERTISE

By 2023, 71% of new cars in key regions will have LDW

Automotive ADAS Applications and Associated Sensors | New Car Penetration Forecast of ADAS Features



- LDW will rely on cameras for the foreseeable future
- Increasing levels of automation will rely also on:
  - High resolution maps
  - Additional sensors (radar, lidar, etc.)
  - Sensor fusion
  - Well defined operating design domains (ODD's)



Source: ADAS Production Forecast Database, March 2018, IHS Markit

3M

LDW: Lane Departure Warning
LKA: Lane Keep Assist

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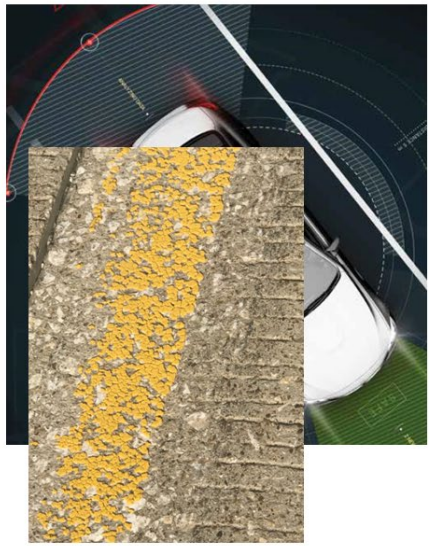
Well defined ODD's should support improved safety

- Minimize transition of control to humans
- Geometric consistency is important for vision systems
- Leverage both liquid and tape based markings
- Maintain performance
  - Over time = durability
  - Reduced maintenance cost
  - Function well in most or all edge conditions
  - Determine and maintain minimums



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INDUSTRY EXPERTISE

Wet-Retroreflectivity = Visibility in rain

Dry Daytime Conditions | Dry Nighttime Conditions | Wet Nighttime Conditions

Yellow Edge Line is optimized for wet reflectivity

White Line & Arrow are not optimized for wet reflectivity

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Contrast is essential

- If there is no contrast the marking is not visible!
- E.G. Light colored (concrete) road surfaces, aged lane markings
- Especially challenging in low angle glare
- Many (most) existing LDW systems ignore negative contrast
- Further research is necessary
  - Humans versus vision systems
  - Contrast configuration

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INDUSTRY EXPERTISE

Ro Gupta

Camera

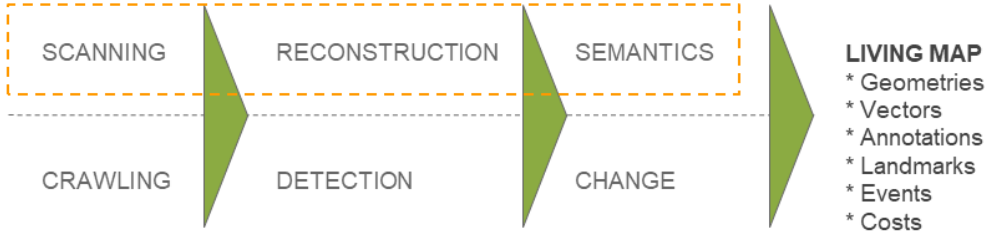
INDUSTRY EXPERTISE

We create dense, < 20 cm accurate base maps via customer or third party LiDAR / RGB scan data anywhere in the world

In addition to getting data from OEM/MaaS customer vehicles, we partner with high coverage fleets, providing video monitoring and safety analytics

We mount inexpensive sensors on those fleet vehicles to collect free high-frequency change detection data

BUILDING A FULL-STACK, LIVING HD MAP



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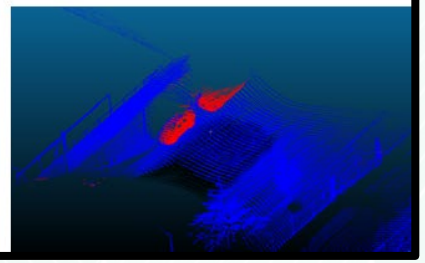
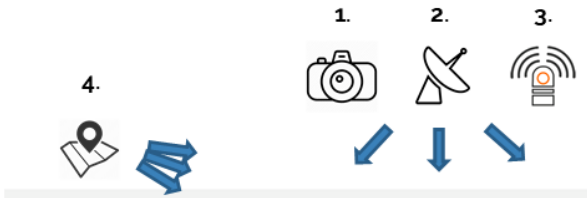
REGISTRATION & PROCESSING / 3D XYZ <> 2D PIXEL SPACE



MAPS AS THE 4TH SENSOR

Baidu 百度 apollo



Map Engine	Localization	Perception	Planning	Control	End-to-End	HMI

Apollo Cyber RT Framework

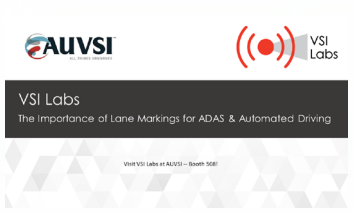
RTOS

INDUSTRY EXPERTISE

Phil Magney

VSI Labs

INDUSTRY EXPERTISE



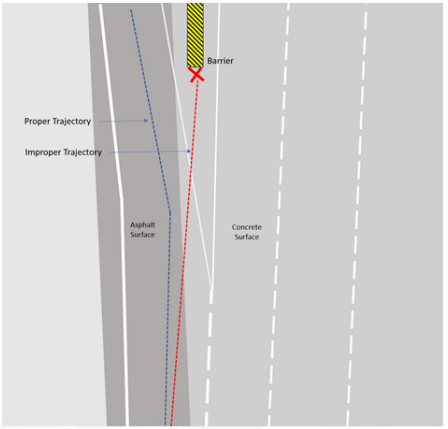
How Do Cars See Lanes

Sensitivity to Lane quality

- Feature-based lane detection
  - The basis for lane departure warning or correction (Hough, Canny Edge)
- Model-based lane keeping
  - Models the lane geometry (RANSAC)
- AI-Based lane keeping
  - Based on trained inference model
- For automated driving you generally calculate a center-line (trajectory)

When Lane Keeping Fails!

- Poor lane markings
- Contrast of two pavement materials
- Driver misuse of system!
- What could have prevented this?
  - Better lane markings
  - A high definition lane model
  - A Driver monitoring system



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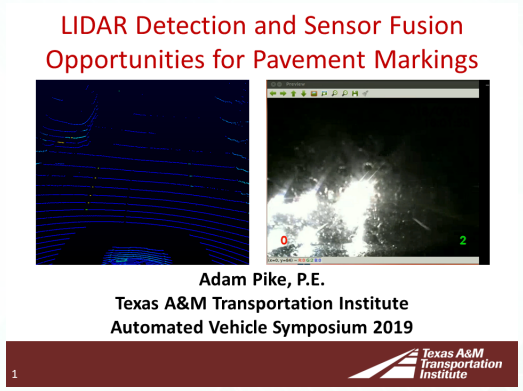

Adam Pike

Texas A&M Transportation Institute

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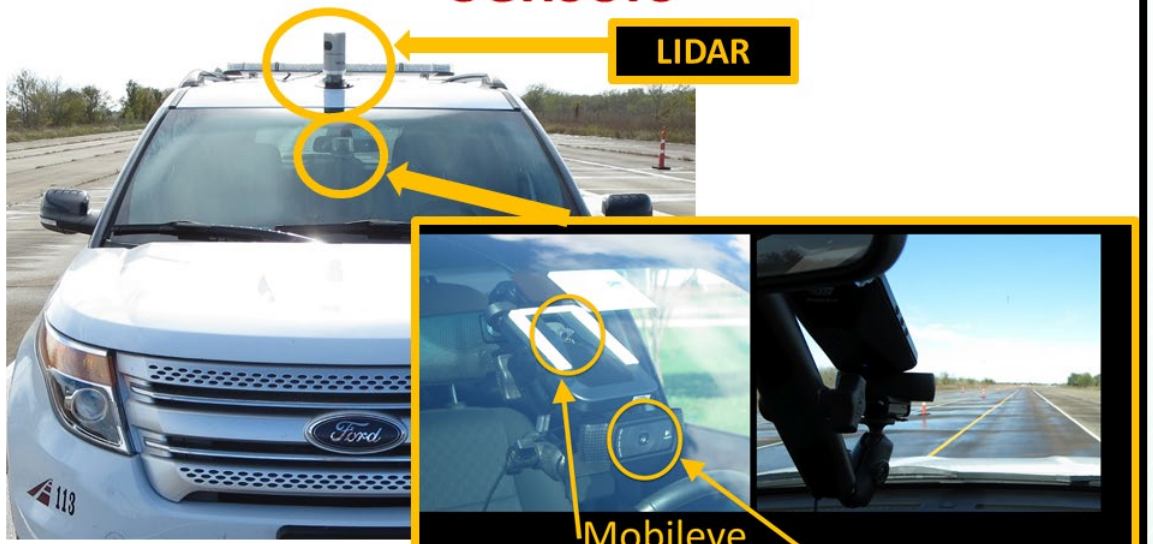
Sensors



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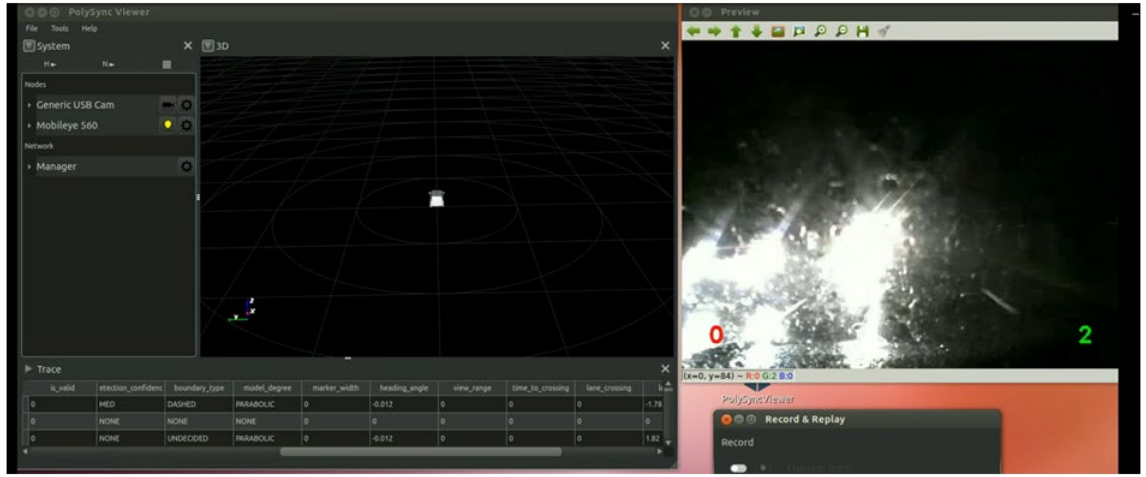
Rainy Oncoming Glare Evaluation



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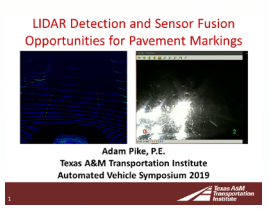
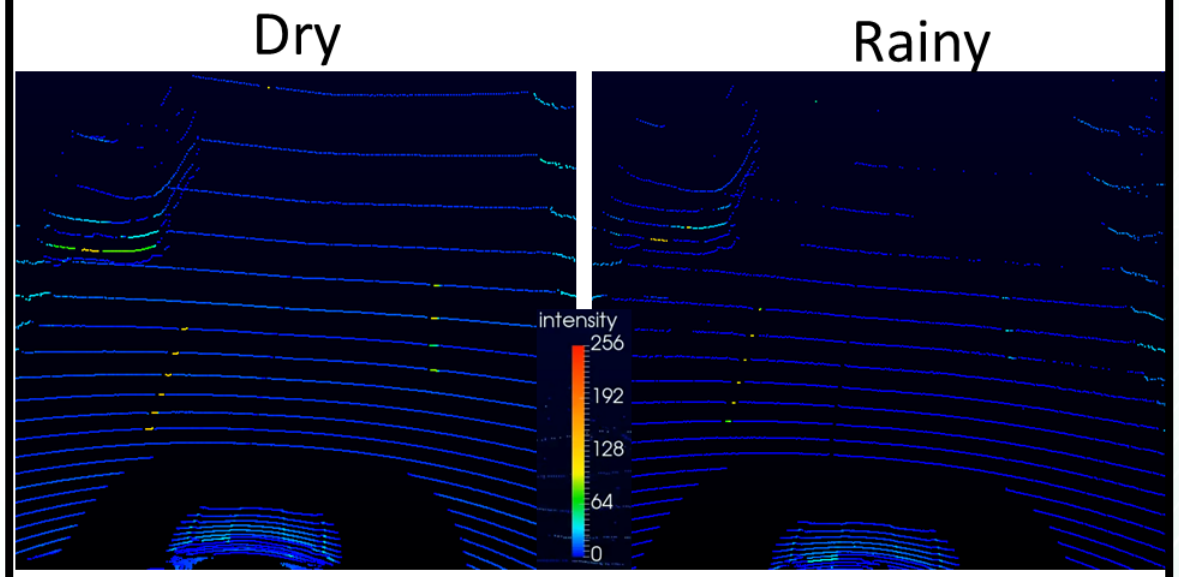


LIDAR Test w/ Glare



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Summary

- Machine Vision
  - Detection confidence is a function of marking characteristics and evaluation conditions
  - Glare negatively impacted detection confidence
    - Markings near glare source were greatly affected
    - Markings on opposite side were affected but to a lesser extent
    - Higher quality markings maintained higher detection confidence levels
- LIDAR
  - Rainy condition impacted return intensity (function of marking R_L)
  - Higher quality markings had higher return intensities
  - Unaffected by glare
  - Rainy detection based on marking having wet reflective properties
- Sensor Fusion (Camera + LIDAR) in combination with adequate markings can overcome the glare conditions evaluated

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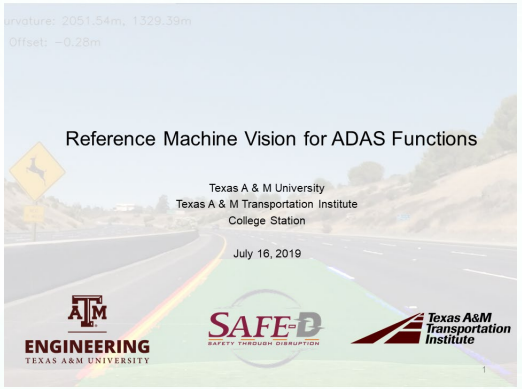

Srivikumar Ranithanam

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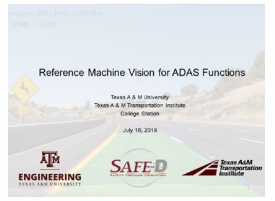

Need for a Reference Vision Based Lane Detection System

Advances in Vision-Based Lane Detection: Algorithms, Integration, Assessment, and Perspectives on ACP-Based Parallel Vision, Xing et al., 2018.

- *"Due to the **lack of ground truth data** and **uniform metrics**, the evaluation of the lane detection system remains a challenge. Since various lane detection systems differ with respect to the hardware and software they use, it is difficult to undertake a comprehensive comparison and evaluation of these systems."*

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Components of a Lane Detection (LD) System

Software	Hardware	Infrastructure
Vision algorithms	Camera	Lane markings

• Preprocessing
• Conventional
  • Feature
  • Model
• Machine learning
• System integration
• Fusion with other sensors (Radar,…)
	• Focal length
	• Field of view
	• Number of pixels
	• Position/Orientation
		• Materials
		• Striping processes
		• Pavement type
		  • Asphalt
		  • Concrete
		• Lane Geometry
		  • Thickness
		  • Length
		  • Continuous
		  • Intermittent

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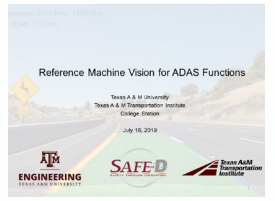

Research Approach

Use large open source data sets available to cover a subset of Operational Domain

Gather field data to cover a subset of the desired Operational Domain

Design and Specify/Build a Test Environment to repeatably achieve a reasonable subset of Operational Domain

Implement Lane Markings in Test Environment

Real Sensors

Wrapper

Detection

Lane Detection Metrics

Lane Markings to be Tested

1. f=12mm/F1.8, Fixed Focal Lens 2 MP
2. f=8mm/F1.4, Manual, 5 MP

Sensors to be Tested

Detection Schemes to be Tested

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2 CULane Dataset

- Videos collected by cameras mounted on six different vehicles driven by different drivers in Beijing
- 9 categories of videos (normal and 8 challenging conditions).
- Each frame, contains manually annotated traffic lanes with cubic splines.
- For cases where lane markings are occluded by vehicles or are unseen, the lanes are annotated according to the context.

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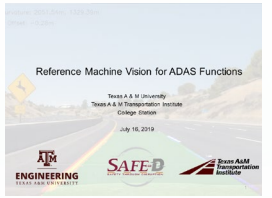

urvature: 2051.54m, 1329.39m
Offset: −0.28m

Algorithms Implementation – CULane Dataset

SCNN

LaneNet

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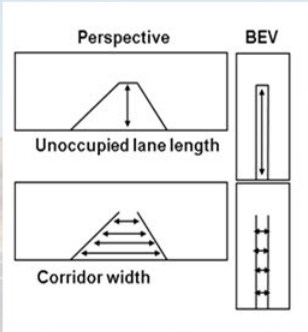
urvature: 2051.54m, 1329.39m
Offset: −0.28m

Metrics

- **Lane Position Deviation (LPD)**
  - Metric to determine the accuracy of the estimated lane in the road scene, especially in the far depth of view from the ego-vehicle.
- **Predicted Lane Geometry**
  - Corridor width, unoccupied length.
- **Cumulative Deviation in Time**
  - Estimate on how the accuracy of the lane estimation process varies in the last 'p' seconds.
- **Computation Efficiency**



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KEY FINDINGS

- Lane markings and delineation are and will remain critical for lateral positioning functions in both ADAS and HAV machine vision systems
- Markings will be used for machine vision for localization by means of perception with visible-light and LiDAR
- Color, width, pattern, material, profile, and position on roadway all influence user perception

Machines are road users!!!

KEY FINDINGS

- State agencies have failed to revise standards for logical consistency (differentiating between two types of dotted lines, for example) and often do not assist local agencies so as to ensure proper use
- Simultaneous Location and Mapping (SLAM) approaches will evolve along with ADAS applications such as LDW and LKA
- There is a substantial need for immediate and near-term investments in research addressing wet-reflective pavement marking visibility to ensure ADAS can evolve into HAV.

KEY RECOMMENDATIONS

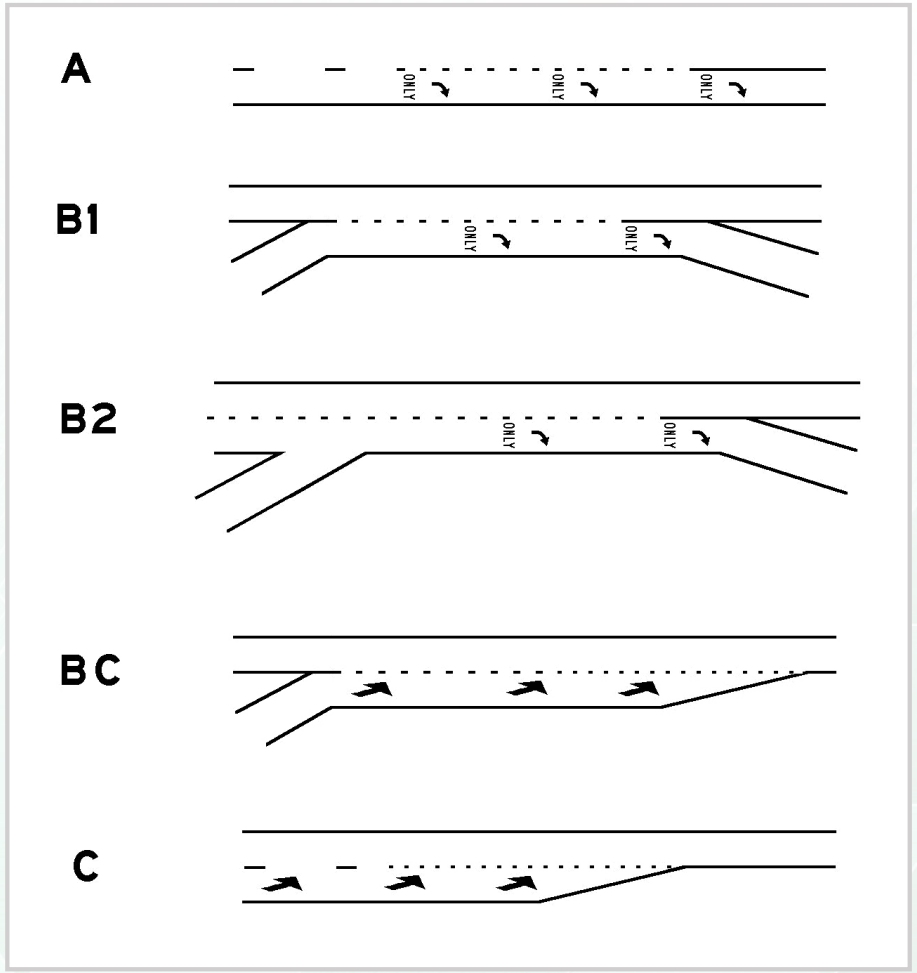
- CONSISTENCY
- DIFFERENTIABILITY
- PERFORMANCE
- MAINTENANCE

CONSISTENCY

CONSISTENCY

DIFFERENTIABILITY

Pattern	Typical Dimension	Use
Broken Lane Line	10' LINE / 30' SPACE 3.3-m LINE / 9.9-m SPACE	separates two continuing lanes
Dotted Lane Line	3' LINE / 12' SPACE 0.9-m LINE / 3.6-m SPACE	separates a continuing lane from a non-continuing lane subject to a downstream mandatory movement
Dotted Extension	2' LINE / 6' SPACE 0.6-m LINE / 1.8-m SPACE	separates a full-width lane from an area of transition, such as a lane development taper for a turn lane, a lane reduction taper, or between turning lanes within an intersection
Solid Line	SOLID	separates a continuing lane from a non-travel lane such as a shoulder or, when wider, separates a continuing lane from a non-continuing auxiliary lane such as a turn lane or other mandatory movement lane or separates lanes designed for restricted use
Double Solid Line	SOLID	separates lanes where crossing from either side is prohibited
Solid Line with Broken or Dotted Lane Line	MIXED	separates lanes where crossing from one side is permitted but crossing from the solid side is prohibited



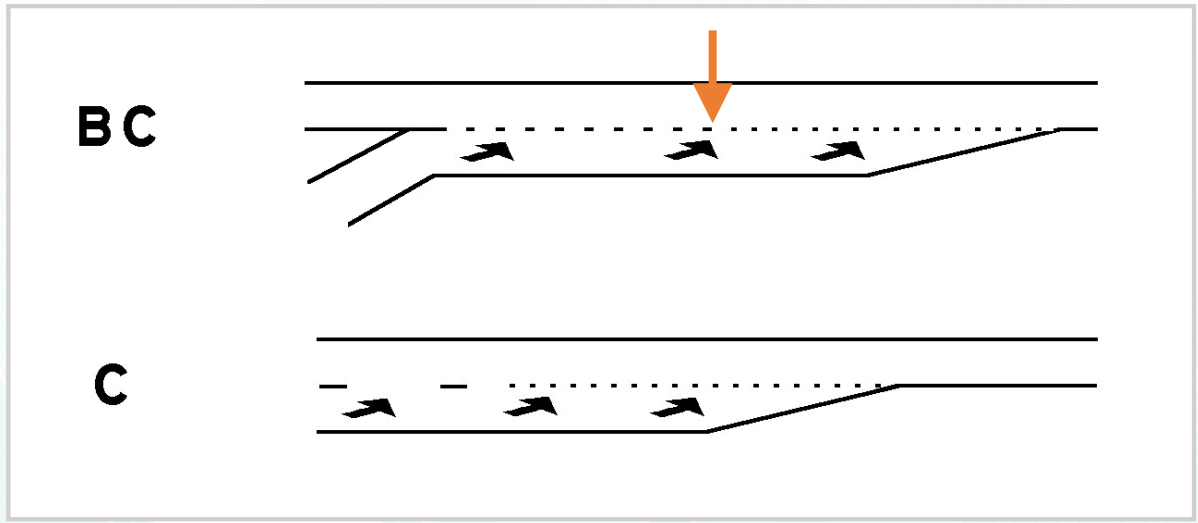
DIFFERENTIABILITY

BROKEN LANE LINE

DOTTED LANE LINE

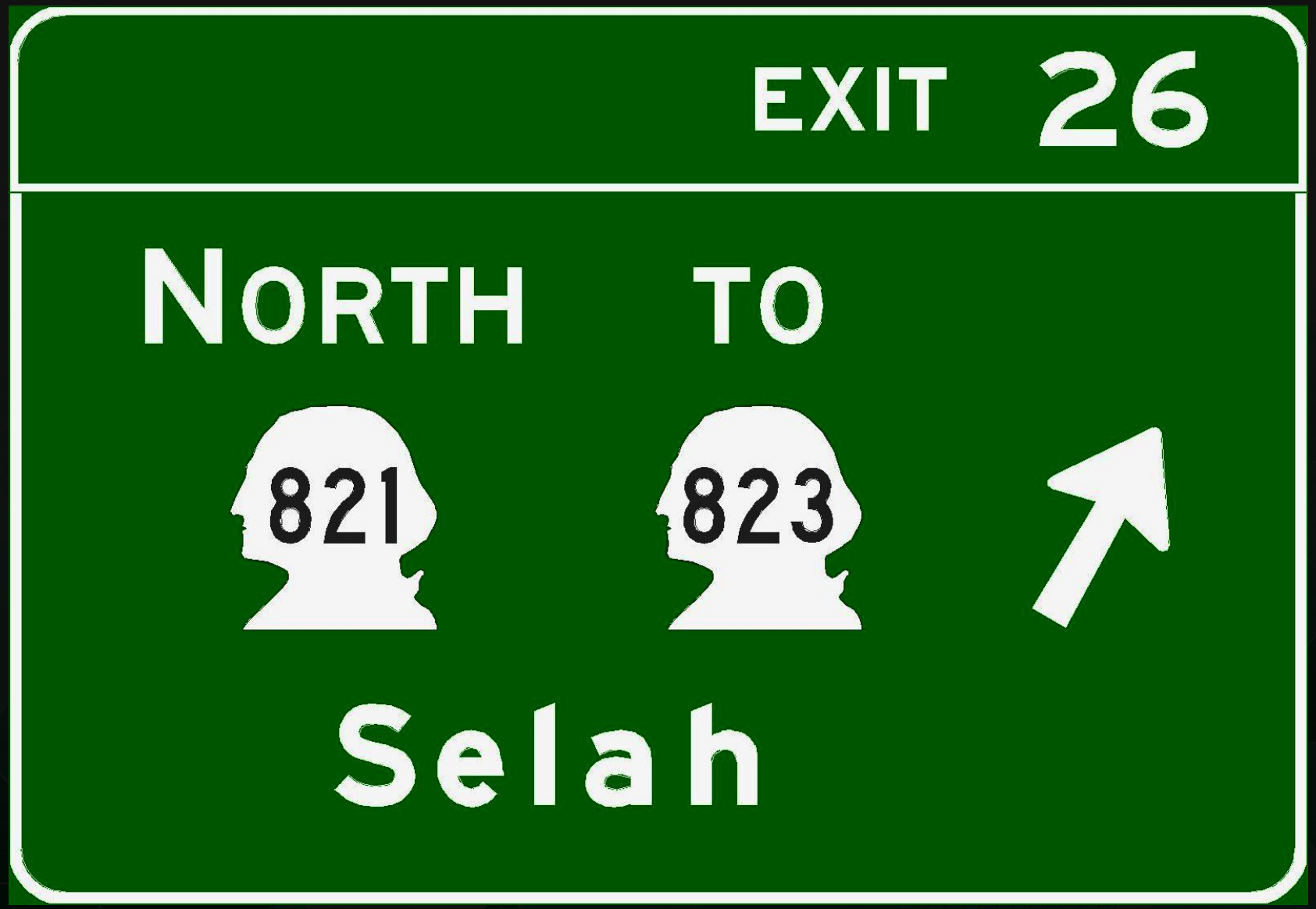
DOTTED EXTENSION

DOTTED . . .



DIFFERENTIABILITY & CONSISTENCY


EXIT 26
NORTH TO
821
823
Selah


EXIT 26
NORTH TO
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PRESIDENT WASHINGTON

STRATEGIC ACTIONS & RESEARCH NEEDS

- Demonstrate the need for agency investment in pavement marking programs
  - technical training
  - improved asset management and maintenance
  - pooled-fund research priorities
  - consistent applications with harmonized standard plans among agencies
- Identify how pavement marking functionality established in the Reference Machine Vision System can aid in establishing standards for lateral positioning systems that use pavement markings *and* also aid human factors research.

STRATEGIC RECOMMENDATIONS

- Determine true machine *and* human ability to differentiate between patterns and widths of pavement mark`ings; assess differentiation between marking patterns with varying ratios
- This recommendation for experimentation is a response to the growing use of 6-inch (200 mm) lane lines, which fall between the 4-inch (150 mm) width used for most broken lane lines and the 8-inch (300 mm) width often used for solid lines in ramp terminal areas.

TECHNICAL RECOMMENDATIONS

Pattern	Typical Dimension	Use
Broken Lane Line	10' LINE / 30' SPACE 3.3-m LINE / 9.9-m SPACE	separates two continuing lanes
Dotted Lane Line	3' LINE / 12' SPACE 0.9-m LINE / 3.6-m SPACE	separates a continuing lane from a non-continuing lane subject to a downstream mandatory movement
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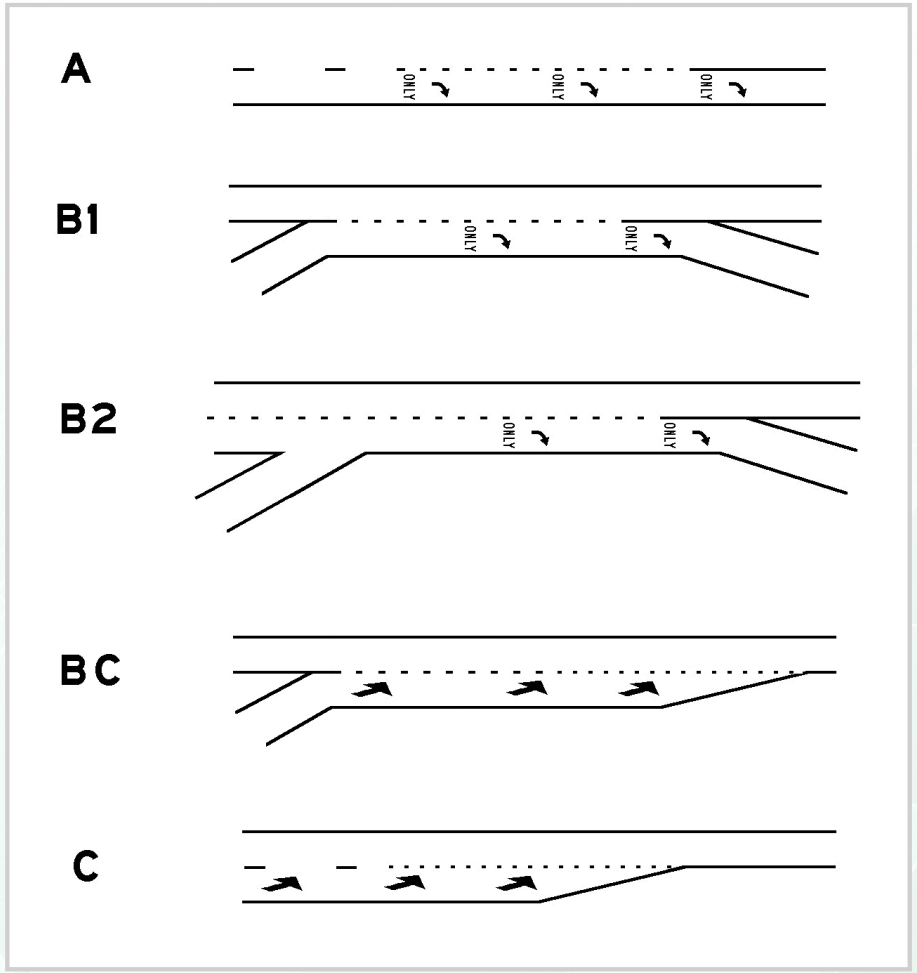
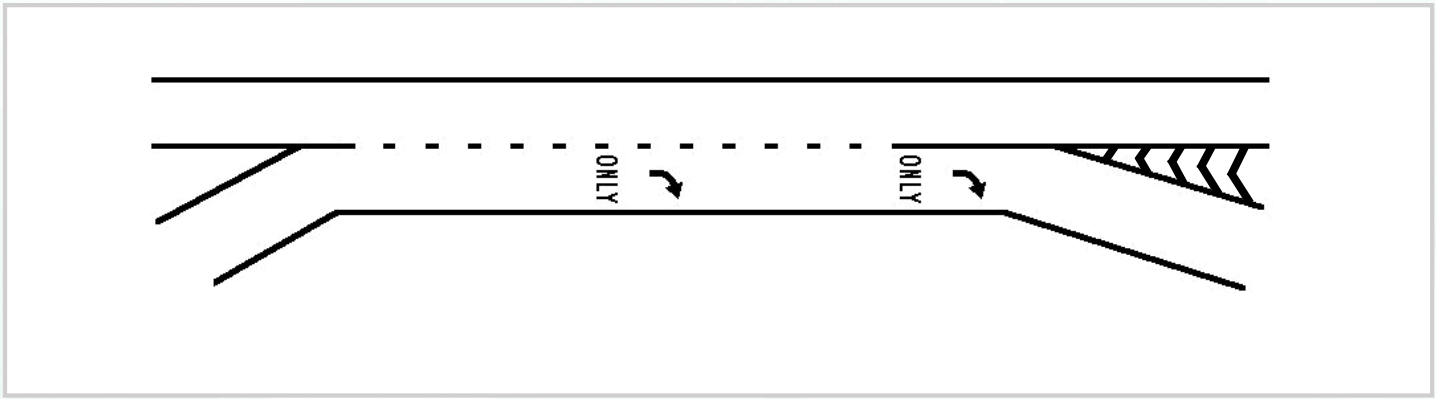


TECHNICAL RECOMMENDATIONS

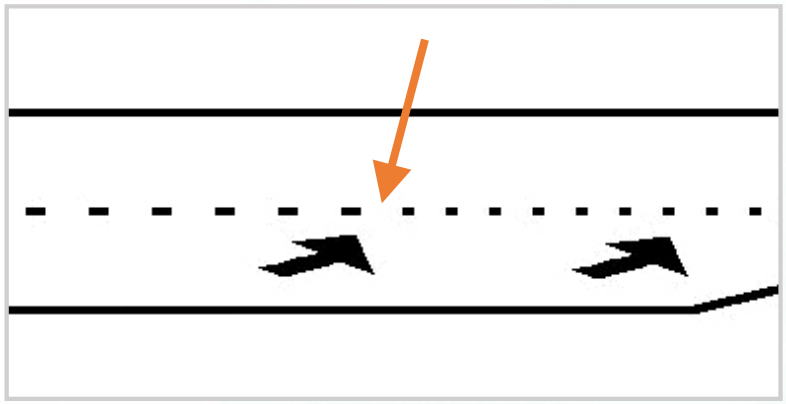
- Identify candidates for conducting pavement marking maintenance and technical training.
- Formulate recommendations for installation of transverse/diagonal markings in all exit and entrance ramp terminal areas, as the number and/or presence of lanes is unclear when the width of the unmarked area of the ramp terminal exceeds 2.7 m (8 ft)

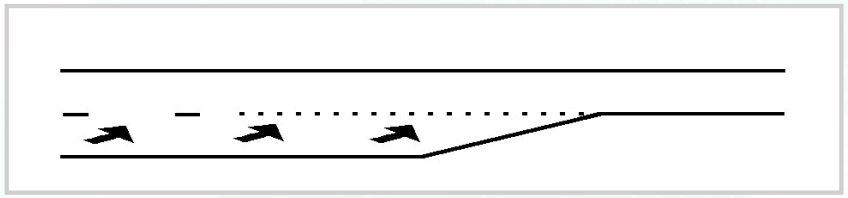
TECHNICAL RECOMMENDATIONS

- Formulate recommendations for installation of transverse/diagonal markings in all exit and entrance ramp terminal areas, as the number and/or presence of lanes is unclear when the width of the unmarked area of the ramp terminal exceeds 2.7 m (8 ft)



TECHNICAL RECOMMENDATIONS





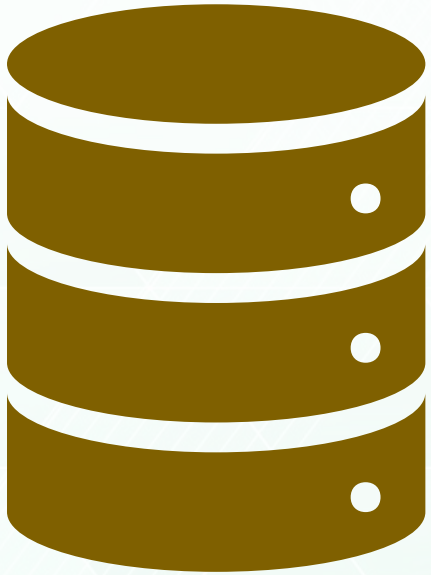
- DIFFERENTIATE between the dotted extension line and the dotted lane line to identify continuing lanes, non-continuing lanes, and transition areas to aid in harmonization of markings with SLAM.
- CONSISTENTLY install dotted extension lines marking all transition areas

FOCUS ON FUNDAMENTALS

WSDOT

"Achieve superior competence in your strategic areas of focus and obtain confidence from manufacturers for deployment here in Washington State."

SENSOR FUSION . . . .



SENSOR FISSION?

INFRASTRUCTURE READINESS

ITS World Congress
Singapore
22 October 2019

KEEP THE CONVERSATION MOVING!

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