NCHRP 20-24(112)
Connected Roadway Classification System Development

Summary of Findings

- Texas A&M Transportation Institute (TTI)
- WSP
- Insightful Leadership
- 3M

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Texas A&M Transportation Institute

wsp

INSIGHTFUL LEADERSHIP with Shelley Row, P.E.

3M Science. Applied to Life.™

Outline

- Background
- CRCS Development Workshop Summary
- CRCS Recommendations
- Maintaining the CRCS
- Future Efforts

Research Objective

- To develop consensus on a CRCS that will be useful to state and local departments of transportation and metropolitan planning organizations that are planning or implementing CV- and HAV-compatible infrastructure.

Research Approach

Develop a **CRCS Framework** that can evolve with

- Technology
- Research findings
- Best practices

Use a **System Perspective** that builds on the

- SAE Automation Levels,
- Capability Maturity Model Style, and
- Readiness of the Marketplace

BACKGROUND

Colorado CRCS – Quick Summary

Level 1 – Roads have nothing

Level 2 – Roads meet AASHTO, MUTCD guidance / standards

Level 3 – Roads have good ITS

Level 4 – Roads have advanced CV environment

Level 5 – Dedicated CV roads or designated lane, removal of traditional TCD

Level 6 – All CV, all roads

EU Effort – INFRAMIX Project

- Includes idea of building on conventional infrastructure
- However, emphasis on infrastructure guiding AVs

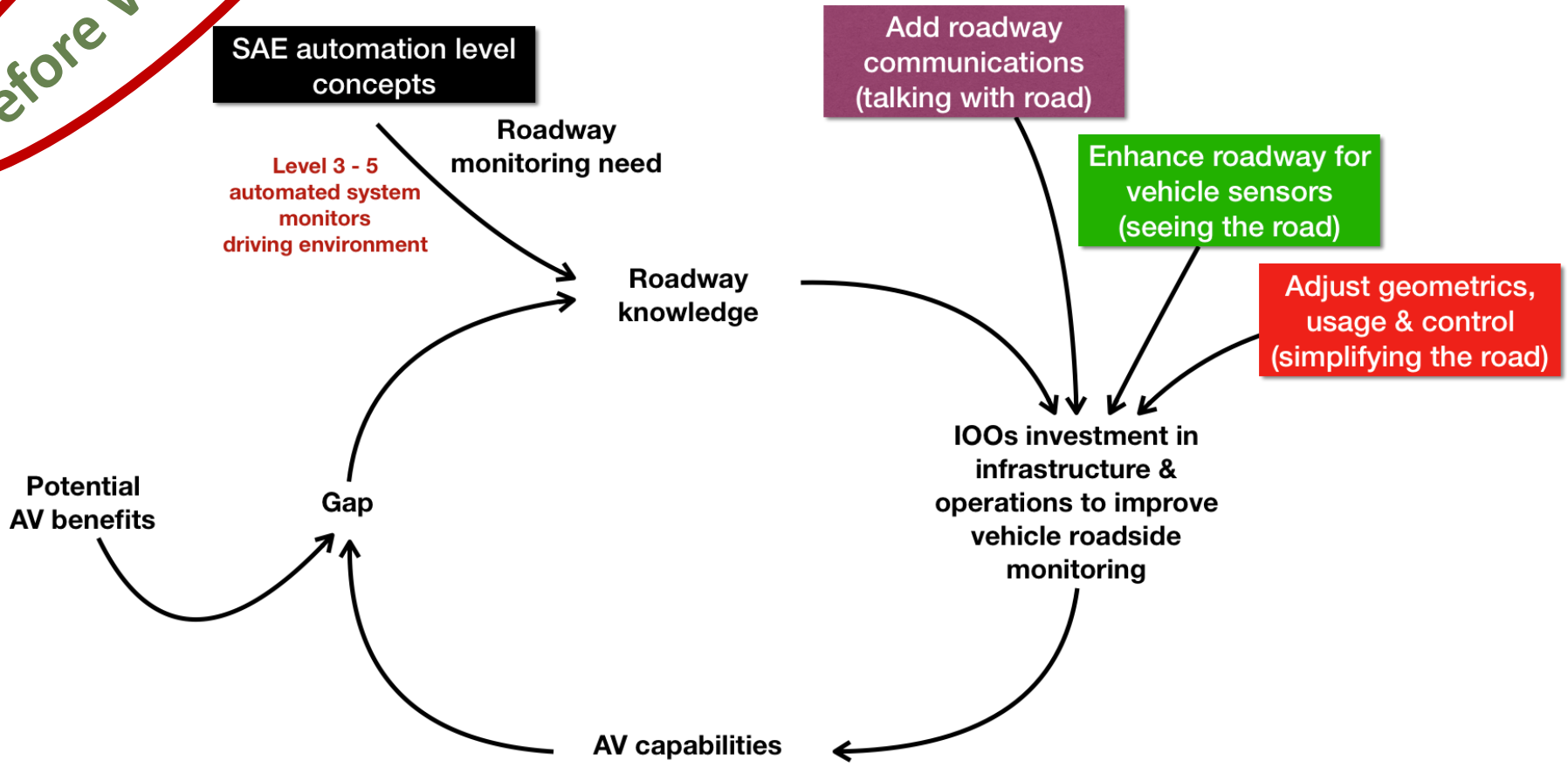
	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				
	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	X			
Digital infrastructure	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	X	X		
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	X	X	X	
	A	Cooperative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	X	X	X	X

Source: Carreras, A. et al, ITS World Congress 2018

CRCS DEVELOPMENT WORKSHOP SUMMARY

Achieving AV Benefits

Before Workshop



Why do we need a CRCS?

- To **communicate effectively** among stakeholders; common language
- System **interoperability** and technology **standardization**
- Investment, policy, and strategic **decision-making**
- To help **navigate gaps** between and within stakeholders (variability in capability and maturity)

Frequent Mentions: ***consistency, interoperable, standardized***

How would you use a CRCS?

- **Planning**, project **prioritization**, and **funding** decisions
- Identifying **CV infrastructure deployments** and future applications
- Exploring **data exchange** and data quality needs for real-time and static data
- Help in **framing the message** for public awareness of infrastructure readiness with level of CAV capability in vehicles

Frequent Mentions: ***prioritization, planning, data***

List one key attribute of a CRCS?

- Standardized **work zone** information
- Current **road conditions** (pavement, weather, traffic, incidents)
- Accommodate **future** advancement of **technologies/capabilities**
- **Standardization** across states

Frequent Mentions: ***uniformity, common language, quality***

Advice from Attendees

- **Keep it simple!**
- Start with high level view and get consensus, then add detail
- Don’t worry about mapping to SAE Levels
- Define/clarify the audience – freeways, arterials, collector/local

Frequent Mentions: ***phased approach, simple, transition***

Detroit Input

Before Detroit

- Use SAE automation concept of roadside monitoring by automated driving system not humans
- Use functional roadway classification terminology
- Embrace the infrastructure activities of:
  - Talking: adding communications,
  - Seeing: improving infrastructure recognition by vehicle sensors,
  - Simplifying: simplifying the environment for automated vehicles

After Detroit

- Add capability maturity model structure similar to TSM&O community
  - Market readiness drives deployment
- Use functional classification terminology (aware of NCHRP 855, Expanded Functional Classification)
- Affirmed utility of talking, seeing, simplifying as strategies to address roadway monitoring
- Keep it simple, implementable
- Revisit periodically, perhaps 5 years

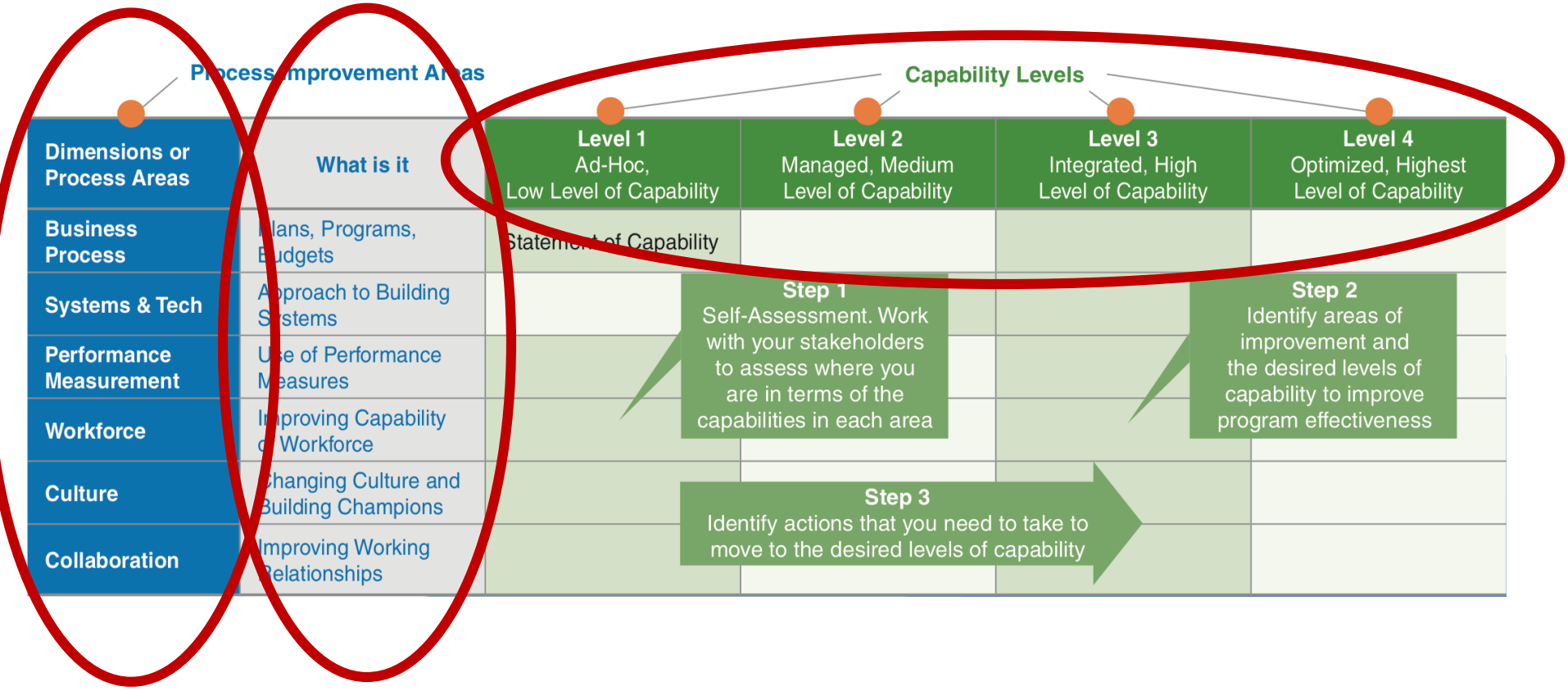
DEVELOPING CRCS FRAMEWORK

IOO Situational Awareness

Foundational inventory

- **Physical assets**
  - Roadway geometrics, signs, pavement markings, traffic signal control, ITS equipment, fiber, RSUs
- **Digital**
  - GIS, Lidar, high-definition maps, as-builts
- **Data**
  - Traffic detection (volumes, speeds, travel times)
  - Traffic signal controller (ATSPM, SPaT)
  - Work Zones, Incident, weather
- **TSMO**
  - ATMS, ATIS, TMC, RWIS, incident mgmt, managed lanes, ramp metering, ATM, ICM, traffic-responsive/traffic-adaptive signals

Capability Maturity Model (CMM) Style



CRCS Assessment Framework

Process Area	What It Is	CRCS Levels			
		Needs Upgrade & Maintenance	Meets Current Best Practices	Meets Emerging Market (2023)	Meets Market 1st Growth Decade
Talking	Electronic communications between vehicles & roadway	• Statement of capability	• Statement of capability	• Statement of capability	• Statement of capability
Seeing	Infrastructure (e.g., signs & markings) readable by vehicle sensors	• Statement of capability	• Statement of capability	• Statement of capability	• Statement of capability
Simplifying	Design & operations for AV vehicles & their uses	• Statement of capability	• Statement of capability	• Statement of capability	• Statement of capability

CRCS Levels

Needs upgrade and maintenance: Design or functionality that falls short or borderline meets existing guidance or recommendations for future technology accommodation

Meets current best practices: Design or functionality that meets existing guidance or recommendations for future technology accommodation

Meets emerging market (1-5 years): Design or functionality that supports early adoption of CV/AV applications or positions the roadway elements for communication/interaction with vehicles

Meets next decade market (10 years): Design or functionality that supports operation of most CV/AV applications and/or communicates/interacts with vehicles proactively

CRCS Assessment Framework

Process Area	What It Is	CRCS Levels			
		Needs Upgrade & Maintenance	Meets Current Best Practices	Meets Emerging Market (2023)	Meets Market 1st Growth Decade
Talking	Electronic communications between vehicles & roadway	T1	T2	T3	T4
Seeing	Infrastructure (e.g., signs & markings) readable by vehicle sensors	S1	S2	S3	S4
Simplifying	Design & operations for AV vehicles & their uses	M1	M2	M3	M4

CRCS Criteria for Talking to the Road

Infrastructure Approach	Infrastructure Element	CRCS Assessment Levels			
		Needs Upgrade & Maintenance	**Meets Current Best Practices**	**Meets Emerging Market (1-5 years)**	**Meets Next Decade Market (10 years)**
Talking Electronic communications between vehicles & roadway	Roadway	No wireline or wireless communication ability	Fiber communication along roadway with access points. Good cellular coverage in corridor	DSRC or C-V2X nodes tied into fiber backbone.	Small cells deployed in roadway right-of-way with good 5G coverage and connection to fiber backbone.
	Traffic Signals	Signal meets MUTCD but internal technology is outdated; no connection	Signal meets MUTCD and is current technology; signal is part of a connected system	Signal is equipped with V2I communication capability (either DSRC or cellular)	Signal transmits SPaT messages consistent with national standards
	Roadside Devices (ITS equipment, DMS, sensors, etc.)	No or limited roadside devices with no communication capability	ITS Equipment (DMS, sensors, ITS cabinets) are tied to fiber backbone or have wireless capability to communicate to TMC.	Infrastructure element is also equipped with capability to communicate data over DSRC or C-V2X	Infrastructure element communicates information on conditions and performance with local processing capability
	Temporary traffic control devices (Cones, barricades, portable DMS)	Traffic control devices are deployed with no communication capability	Temporary traffic control devices are equipped with cellular communication capability	Portable infrastructure element is equipped with technology that has the capability to communicate	Portable infrastructure element communicates information on conditions and performance

CRCS Criteria for Seeing the Road

Infrastructure Approach	Infrastructure Element	CRCS Assessment Levels			
		Needs Upgrade & Maintenance	**Meets Current Best Practices**	**Meets Emerging Market (1-5 years)**	**Meets Next Decade Market (10 years)**
Seeing Infrastructure (e.g., signs & markings) readable by vehicle sensors	Roadway	Roadway assets are not recorded in digital form	Digital inventory of roadway assets exist	Major corridors or areas have digital maps.	All roadways are digitally mapped.
	Signs	Signs may not be present or if they are present may lack desired visibility based on retroreflectivity guidance	Signs meet desired visibility based on retroreflectivity guidance	Signs provide visibility needed for CV/AV recognition	Signs include technology that provide for future machine visibility and processing
	Marking	Markings may not be present or, if they are present may lack desired visibility based on retroreflectivity guidance; Markings are not present	Markings meet desired visibility based on retroreflectivity guidance ; Markings are present.	Markings are present and consistent (lane and edge lines) and provide visibility needed for CV/AV recognition in terms of reflectivity and contrast.	Markings include technology that provide for future machine visibility and processing
	Traffic Signals	Traffic signals are in need of upgrade or maintenance.	Traffic signal equipment meets MUTCD requirements	Signal heads are consistent in design and use of technology. Use of back plates to eliminate glare. Removal of all visual obstructions.	Research is needed

CRCS Criteria for Simplifying the Road

Infrastructure Approach	Infrastructure Element	CRCS Assessment Levels			
		Needs Upgrade & Maintenance	**Meets Current Best Practices**	**Meets Emerging Market (1-5 years)**	**Meets Next Decade Market (10 years)**
Simplify Design & operations for AV vehicles & their uses	Roadway	Infrastructure geometry may not meet AASHTO guidelines. Pavement in poor condition.	Infrastructure geometry meets AASHTO guidelines. At least one full shoulder. No pavement defects.	Infrastructure geometry is designed to facilitate navigation by CV/AVs	Infrastructure geometry is specifically designed to accommodate navigation and operation of CV/AVs
	Temporary Roadway Geometry (work zones, utility zones)	Minimal navigational aids (cones, barricades, etc.) are available to define temporary geometry	Navigational aids (cones, barricades, etc.) for temporary geometry are in compliance with the MUTCD	Navigational aids (cones, barricades, etc.) for temporary geometry are in compliance with the MUTCD and are equipped with communication technology for V2I and are designed to be visible for CAVs	Navigational aids (cones, barricades, etc.) for temporary geometric changes communicate with vehicles and are designed to support CAV navigation and operations
	Low-speed Environments	No designation of zone or district for CAVs.	Infrastructure geometry meets design guidance and traffic control devices meet MUTCD.	Research is Needed	Research is Needed
	Dedicated Facilities	No designation for a dedicated CAV facility.	Managed lanes that have user requirements for access.	Research is Needed	Research is Needed

CRCS Framework Overview

Infrastructure Approach	What It Is	CRCS Levels			
		Needs Upgrade & Maintenance	**Meets Current Best Practices**	**Meets Emerging Market (1-5 years)**	**Meets Next Decade Market (10 years)**
Talking	Electronic communications between vehicles & roadway	• Limited or no fiber installed • Limited or no cellular coverage • Limited or no roadside devices with communication • Signal equipment outdated with no connections • Temporary TCD deployed with no communication	• Fiber along roadway with access points • Good cellular coverage • Updated signal controller, meets MUTCD, connected as part of system • Infrastructure has no V2I capability • TCDs connected	• DSRC or C-V2X nodes tied into fiber • Signal is equipped with V2I communication capability • Infrastructure has V2I capability • TCDs able to connect to cellular or fiber	• Small cells deployed along roadway with 5G coverage • Signal transmits SPaT messages • Infrastructure transmits information on conditions with local processing capability
Seeing	Infrastructure (e.g., signs & markings) readable by vehicle sensors	• Roadway assets are not in digital form • Signs and markings are either not present and/or fall short of MUTCD retroreflectivity guidance • Signals in need of upgrade	• Digital inventory of roadway assets exist • Signs and markings are present and meet MUTCD retroreflectivity guidance • Traffic signal equipment meets MUTCD	• Major corridors or areas have digital maps • Signs and markings meet revised MUTCD CAV visibility guidance • Signals are consistent, visible and use glare reduction backplates	• Signs and markings include technology that provide for future machine visibility and processing • Research needed on how AVs see signals
Simplifying	Design & operations for AV vehicles & their uses	• Infrastructure geometry, temporary TCDs, and permanent TCDs may not meet AASHTO or MUTCD guidelines • Pavement in poor condition	• Infrastructure geometry meets AASHTO design guidance • Pavement free of defects • Temporary and permanent TCDs meet MUTCD guidance	• Infrastructure geometry is designed to facilitate navigation by CV/AVs • Navigational aids are V2I capable • Research needed	• Infrastructure geometry and navigational aids are specifically designed for CV/AVs only • Research needed

MAINTAINING CRCS AND RESOURCES

CRCS Maintenance

- There are gaps in knowledge about infrastructure impacts on CAVs
  - Current and future research will help fill gaps
- Recommend updating every 5 years
- Need an organization to lead CRCS maintenance
- Discussions on content updates should be facilitated in neutral and transparent venue
- Updates should reflect research findings and CRCS implementation best practices
- Many resources that will contribute to updates

Talking to the Road Resources

Need Categories	Resource	When	Note
Equipment – Vehicles and Infrastructure	SPaT Challenge	Deployment in 50 states at 20 intersections by 2020	
Deployment capability (specs, testing plans, etc.)	SPaT Challenge resource documents	Being populated now on National Operations Center of Excellence website	https://transportationops.org/spatchallenge/resources
Applications - initial applications developed with OEMs & IOOs	CAT V2I Deployment Coalition IOO/OEM Forum priorities	Circa 2020 - Red light running	Others in process
Institutional Readiness - enabling legislation	National Conference of State Legislatures (NCSL) – tracking of legislation		
Standards	SAE J2735 Message Set Dictionary NCTCIP Standard Set	SAE J2735 available now. NTCIP standards available now.	

Seeing the Road Resources

Need Categories	Resource	When	Note
Equipment – Vehicles and Infrastructure	ATTSA – Evaluation of Pavement Marking Width on Detectability By Machine Vision	2018	Report looks at 4-inch versus 6-inch markings
	NCHRP 20-102(06) – Road Markings for Machine Vision	Publication due in 2019	Report looks at Machine Vision performance for various road marking use cases
Deployment capability (specs, testing plans, etc.)	NCUTCD CAV Task Force	2019	TCD suggestions for automated driving systems
	NCUTCD Task Force on Traffic Signals	2020	Develop AV readiness checklist
Applications - initial applications developed with OEMs & IOOs	None at this time		
Institutional Readiness - enabling legislation	National Strategy for Highway Automation (AASHTO Task Force on Highway Automation)	2019/2020	Seeking inclusion in next transportation bill reauthorization.
Standards	MUTCD Part 3 - Markings	Balloting in 2019	

Simplifying the Road Resources

Need Categories	Resource	When	Note
Equipment – Vehicles and Infrastructure	NCHRP 20-102(21) – Infrastructure Modifications to Improve the Operation Domain of AVs	In development	Relates to simplifying the ODD for AV operations
	NCHPR 20-102(24) – Infrastructure Enablers for CAVs and Shared Mobility	In development	Relates to infrastructure to help CAVs talk and see the road
	NCHRP 29-24(102) – Readiness Framework: Coast-to-Coast Automated Mobility by 2025	In development	Relates to addressing AV readiness
	NCHRP 20-102(15) Impacts of CAV Technologies on the Highway Infrastructure	In development	Relates to CAV impacts on infrastructure
Deployment capability (specs, testing plans, etc.)	None available		
Applications - initial applications developed with OEMs & IOOs	USDOT Report – Low-Speed Automated Shuttles: State of the Practice	2018	Provides examples of the ODDs with AV deployments
Institutional Readiness - enabling legislation	NCHRP Report 891 – Dedicating Lanes for Priority or Exclusive Use by CAVs	2018	Reviews laws and regulation regarding dedicated lanes
Standards	No specific standards for these ODDs		

USING THE CRCS

Current Knowledge – Graphical Snapshot

Process Area	What It Is	CRCS CMM Capability Levels			
		Needs Upgrade & Maintenance	Meets Current Best Practices	Meets Emerging Market (2023)	Meets Market 1st Growth Decade
Talking	Electronic communications between vehicles & roadway				
Seeing	Infrastructure (e.g., signs & markings) readable by vehicle sensors				
Simplifying	Design & operations for AV vehicles & their uses				

CRCS Condition Report (%)

Process Area	What It Is	CRCS Capability Levels for Principle Arterials in Neighborhood ZZZ			
		Needs Upgrade & Maintenance	Meets Current Best Practices	Meets Emerging Market (2023)	Meets Market 1st Growth Decade
Talking	Electronic communications between vehicles & roadway	T1 XX%	T2 XX%	T3 XX%	T4 XX%
Seeing	Infrastructure (e.g., signs & markings) readable by vehicle sensors	S1 XX%	S2 XX%	S3 XX%	S4 XX%
Simplifying	Design & operations for AV vehicles & their uses	M1 XX%	M2 XX%	M3 XX%	M4 XX%

CRCS Assessment/Investment Framework

Process Area	What It Is	CRCS Assessment/Investment for City XYZ Major Arterials			
		Needs Upgrade & Maintenance	Meets Current Best Practices	Meets Emerging Market (2023)	Meets Market 1st Growth Decade
Talking		XX% $xxx,xxx / XX% $xxx,xxx	XX% $xxx,xxx / XX% $xxx,xxx	XX%	XX%
Seeing		XX% $xxx,xxx / XX% $xxx,xxx			
Simplifying					

Future Recommended Efforts

- Identify a CRCS champion (e.g., AASHTO, ITE, TRB, NOCoE)
- Have agencies apply CRCS to their roadway system
  - First step is to conduct an agency situational awareness of their infrastructure, data, and systems
- Establish a CRCS maintenance plan
- TRB/AASHTO map current research to gaps in CRCS knowledge base
- Require TRB CAV research needs statements to identify potential for adding knowledge to CRCS
  - Similar to AASHTO Green Book process
- Communication of CRCS concept to public audiences
  - May need to be modified to public facing information

Future Research

- AV sensor performance for a greater range of pavement marking condition use cases
- Methodology for determining AV readiness of pavement markings
- AV sensor and software performance in perceiving traffic signals
- Performance, infrastructure needs, costs of various V2I communications options
- Performance and bandwidth use for multi-communication environments.
- Purpose-driven roadway design for CAVs