

Towards a Safe System Design for Physical Infrastructure in the Era of CCAM

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ABSTRACT

The transition from human-driven vehicles to Connected, Cooperative, and Automated Mobility (CCAM) systems requires a shift in the way physical infrastructure is designed, managed and maintained. The safe system design should provide a base for that transition by prioritizing, preventing and reducing crashes using a systemic approach, where physical infrastructure, such as roadways, signage, traffic signals, and maintenance, integrates seamlessly with Autonomous Vehicles (AVs) technology to minimize risks and enhance safety for all road users. While the traditional Safe System Design (SSD) focused on human-centered transportation systems, its adaptation to CCAM should redefine the role of infrastructure to support both human-driven and automated vehicles. This paper presents a framework for the safe system design of physical infrastructure for CCAM deployment. This approach is based on an extensive literature review and synthesis of scientific papers, standards, and technical reports. From this review, five principles can be identified as the foundation of the SSD for CCAM systems: (1) Risk mitigation through enhanced infrastructure, (2) Operational Design Domain (ODD) expansion, (3) Seamless integration of mixed traffic, (4) Long-term scalability and global compatibility and (5) Integration of technology-driven infrastructure. Together, these principles establish a way for integrating the SSD with CCAM infrastructure planning. The proposed framework is conceptual and intended as a basis for future development and validation of infrastructure readiness assessment frameworks that can guide policymakers, infrastructure managers, and system designers in prioritizing investments for safe and scalable CCAM deployment.

INTRODUCTION

- Road traffic crashes remain a major global safety challenge.
- The Safe System Design (SSD) approach aims to prevent fatalities through shared responsibility between road users and system designers.
- At the same time, Connected, Cooperative and Automated Mobility (CCAM) is transforming transport systems.

Problem

Current infrastructure was mainly designed for human perception, while Automated Vehicles (AVs) depend on readable, consistent, and digitally supported environments.

Research Gap

Existing studies focus either on:

- Infrastructure requirements for AVs, or
- Safe System principles

but lack an integrated framework linking SSD with infrastructure requirements for CCAM and ODD expansion.

Aim

To propose a conceptual Safe System Design framework for physical infrastructure in the era of CCAM.

METHODOLOGICAL APPROACH

Structured Literature Review & Narrative Synthesis

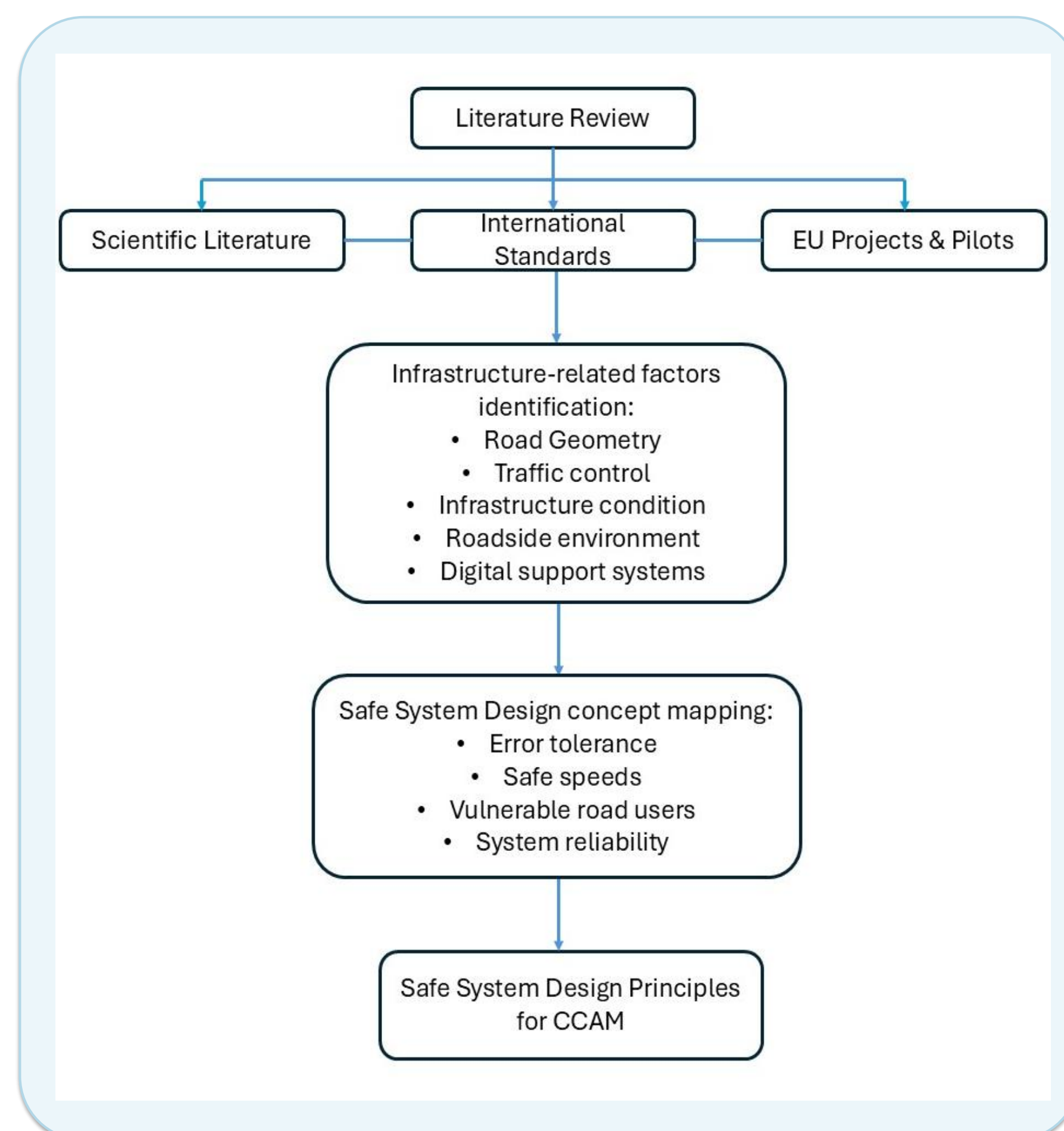
The framework was developed through synthesis of:

- Scientific Literature
- International Standards
- Technical Reports
- EU-funded Projects

Main Research Domains

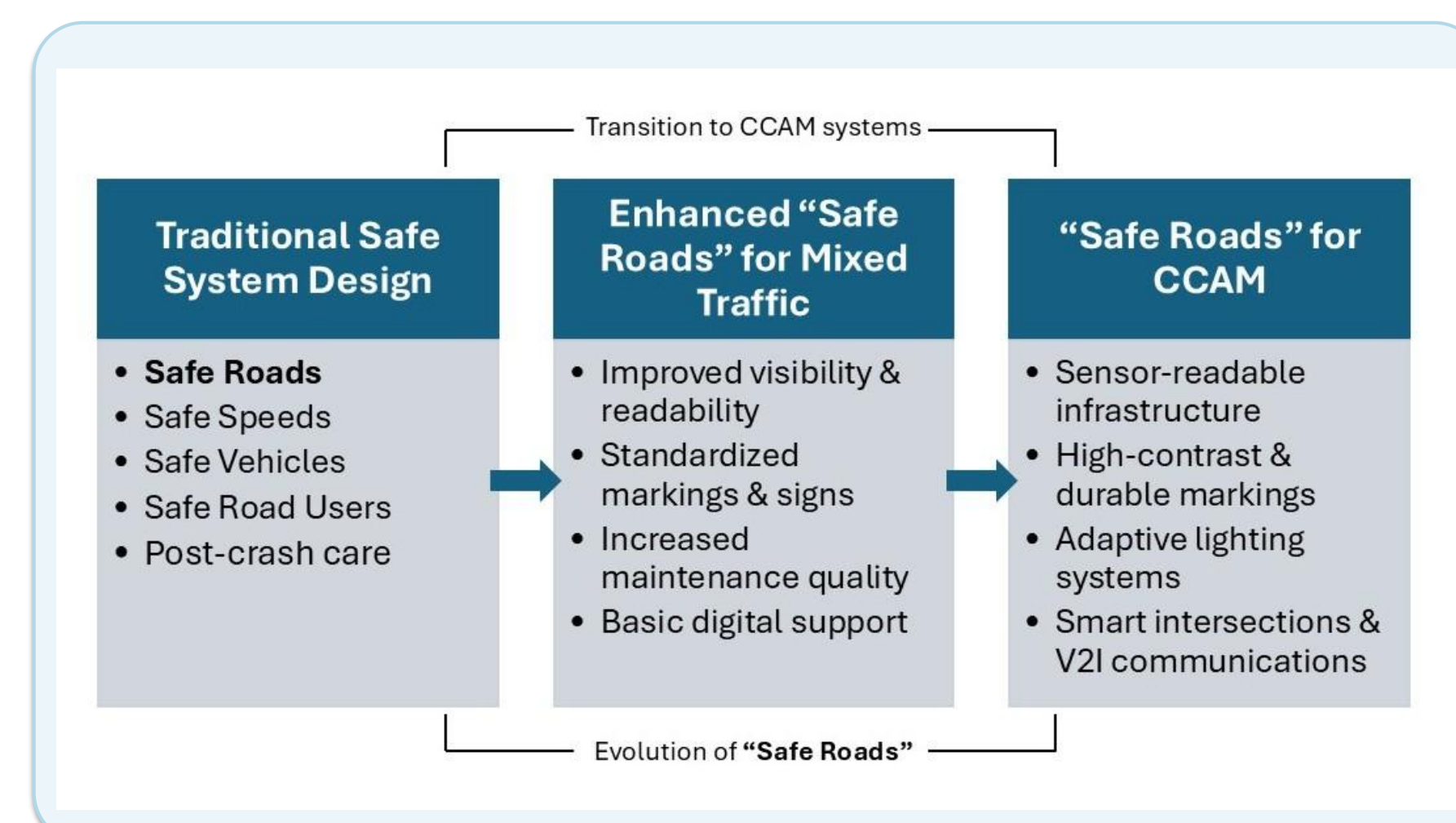
- Safe System Design
- Infrastructure requirements for AVs
- Operational Design Domains (ODDs)

Workflow Diagram

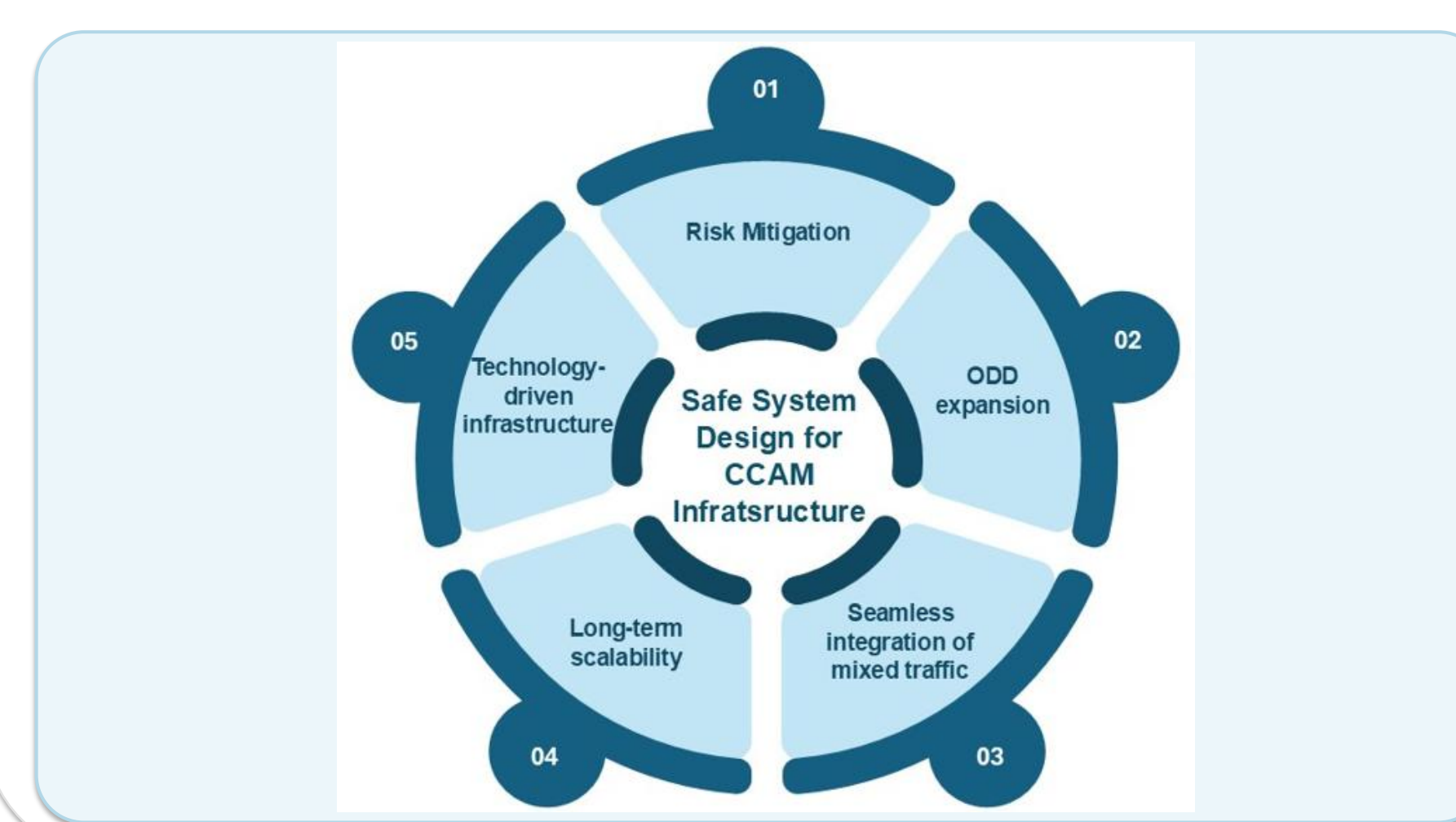


SSD FRAMEWORK FOR CCAM

Safe Roads Evolution



Five Safe System Design Principles for CCAM



1. Risk Mitigation Through Enhanced Infrastructure

- ✓ Clear markings & signage
- ✓ Safe speeds
- ✓ Road maintenance
- ✓ Consistent road geometry

Impact: Improved perception, reduced crash risk

2. ODD Expansion

- ✓ Geofencing
- ✓ Adaptive lighting
- ✓ Dedicated AV infrastructure
- ✓ Dynamic routing support

Impact: Operation in more diverse conditions

3. Seamless Integration of Mixed Traffic

- ✓ Smart intersections
- ✓ V2I communication
- ✓ Adaptive traffic management
- ✓ VRU protection

Impact: Reduced conflicts, safer interaction

4. Long-Term Scalability & Global Compatibility

- ✓ Modular infrastructure
- ✓ Standardization
- ✓ Cross-region interoperability

Impact: Cross-region operation, future readiness

5. Technology-Driven Infrastructure

- ✓ Technology-Driven Infrastructure
- ✓ HD Maps
- ✓ Digital signage
- ✓ Cybersecurity & fail-safe systems

Impact: Better situational awareness

CONCLUSIONS

Main Findings

- Proposed a conceptual SSD framework for CCAM infrastructure
- Identified five key principles for safe and scalable deployment
- Connected Safe System concepts with infrastructure requirements for automated mobility
- The framework can support infrastructure planning, CCAM readiness assessment
- Investment prioritization

Future Work

- Development of measurable indicators
- Case study applications
- Validation in real-world CCAM environments

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