Vehicular Communications for Merging Automatically into Congested Lanes

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The problem: Automated Vehicles still struggle where traffic becomes social

Congestion and VRU-dense areas create situations that perception alone cannot always resolve.

In open traffic, a gap is found.
In congestion, a gap must be given.

- Human drivers negotiate by eye contact, nudging and local custom
- ADS must avoid unsafe assumptions about intent
- Without cooperation, a vehicle may reach the end of the ramp and become stranded

The core question: what cooperative information is safety-relevant, trustworthy and available in time?

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Why merging in congestion is a hard automation problem

The maneuver combines traffic law, human behavior, sensor limits and communications reliability.

WG1 guiding principle: merge only when safety requirements are met.

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Detect — **Interpret** — **Negotiate** — **Commit**

No usable gap	Traffic may be legal but physically too dense.
Priority differs by jurisdiction	Rules for ramps, zipper merge and shoulder use vary.
Intent is hidden	The AV cannot assume a human will cooperate.
Do-not-strand risk	End-of-lane behavior must be safe and predictable.

How WG1 explored the problem: a safety-first systematics view

The completed systematics work treated communication as one input to a functionally safe decision chain.

1 Sense
On-board sensors
+ received data

2 Know the rules
Traffic rules
+ legal signals

3 Coordinate
V2V / V2I
ITS messages

4 Merge safely
Only when
safety criteria pass

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Message families evaluated

- CAM / BSM
- CPM
- DENM
- IVIM
- MCM / MSCM

From the beginning, the question was not “more data?” but “which data is safe, timely, legal and interoperable?”

What the ITS messages contribute — and where the limits appear

The value is cooperative context; the challenge is proving it under congestion, latency and trust constraints.

Awareness	Collective perception	Events & infrastructure	Maneuver coordination
CAM / BSM Who is nearby? Speed, heading, status	CPM What can others see? Occluded objects, VRUs	DENM / IVIM What changed? Hazards, signs, legal layer	MCM / MSCM Who intends to yield? Coordinated gap creation

Useful information is not automatically usable information.

- **Functional safety**
- **Security & trust**
- **Positioning integrity**
- **QoS / determinism**

A received message must be correct, authentic, timely, semantically aligned and legally meaningful before it can influence the maneuver.

Infrastructure matters when “advice” becomes a legal signal

WG1 looked at how traffic rules, markings, signals and messages must align in real driving behavior.

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Written rule
Country rules + local practice

↓

Roadside signal
Signs, markings, ramp meters

↓

Digital message
IVIM / DENM — legal + event layer

↓

ADS decision
Merge · wait · do not strand

Key insight: the AV needs a machine-readable picture of the legal context — not just sensor observations.

The shift: from “messages are useful” to “the system is not yet adequate”

WG1 translated gaps into requirements for automated lane merging and the 2030–2060 horizon.

Each inadequacy → a verifiable requirement, before deployment

Functional safety
Do-not-strand assurance

Spectrum & QoS
Sized for peak load

Determinism & latency
Bounded worst-case delay

Metadata & receipt
Confidence + acknowledgement

Security & PQC
Crypto-agile lifecycle

Positioning integrity
Lane-level + confidence

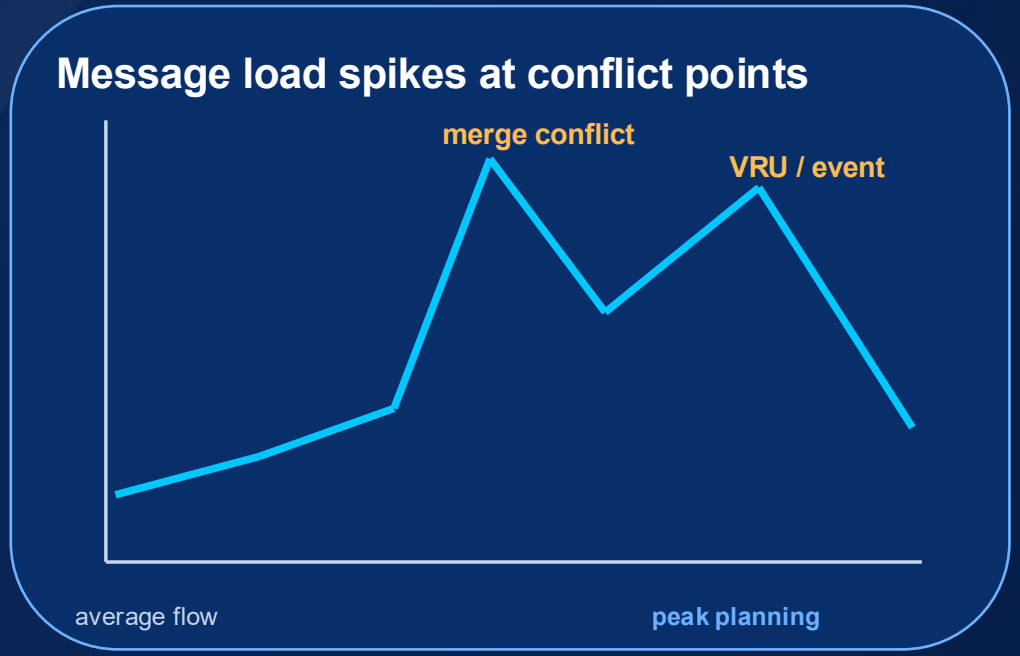
Infrastructure readiness
Digital, authenticated assets

Interoperability
Stable across generations

The emerging answer: plan for peak/congested volumes, interoperable profiles, safety-case integration and crypto-agile security.

Worst-case planning: averages are not enough

Safety-critical cooperation must be dimensioned for peak-hour, event-driven and VRU-rich scenarios.



Peak-hour merge
Dense vehicles, small gaps, many coordination attempts

Event spike
Stadium, roadworks or incident creates abrupt demand

Urban canyon / tunnel
GNSS and perception gaps persist

Mainstream CPM
High-density sensor sharing stresses spectrum and compute

WG1 is enumerating the “best of the worst-case” details so requirements can be dimensioned, not guessed.

Heavy VRU zones expose the same cooperation gap

The same principles matter where vehicles, pedestrians, cyclists and buses share constrained space.

Congested urban space is a networked safety problem.

VRUs are frequently occluded
Traffic intent changes quickly
Infrastructure capability is uneven
Trust boundaries cross industries

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Same maneuver, different law: merging rules across regions

WG1’s ongoing jurisdictional analysis informs worst-case message-size and spectrum planning.

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Key insight

Same maneuver, different law. Pragmatic regulation can solve a technology problem — and message planning must absorb that variation.

Sweden · Mutual adaptation
No absolute priority — drivers cooperate; relies on social compliance.

United States · Early vs late merge
Zipper cuts congestion; ramp metering widely deployed and effective.

Switzerland · Do-Not-Strand (best practice)
Zipper law + adapted markings; a stranded vehicle is now rare.

Austria · Strict right-of-way
Motorway traffic has priority — clear, but higher AV-stranding risk.

Denmark · Shared responsibility
“Where the lines disappear, drivers merge” — both adapt; needs coordination.

WG1 status: from completed foundations to actionable planning

The work is moving from systematics and inadequacy analysis to jurisdictional rules and worst-case dimensioning.

Target: document completion by December 2026

Outcome: cooperative mobility, safely deployed

A requirements path for industry and authorities.

What success looks like

1. AVs can avoid unsafe stranded states
2. Communications are integrated into safety cases
3. Messages are interoperable across regions
4. Spectrum and infrastructure plans match real peaks
5. Regulators and industry align before deployment

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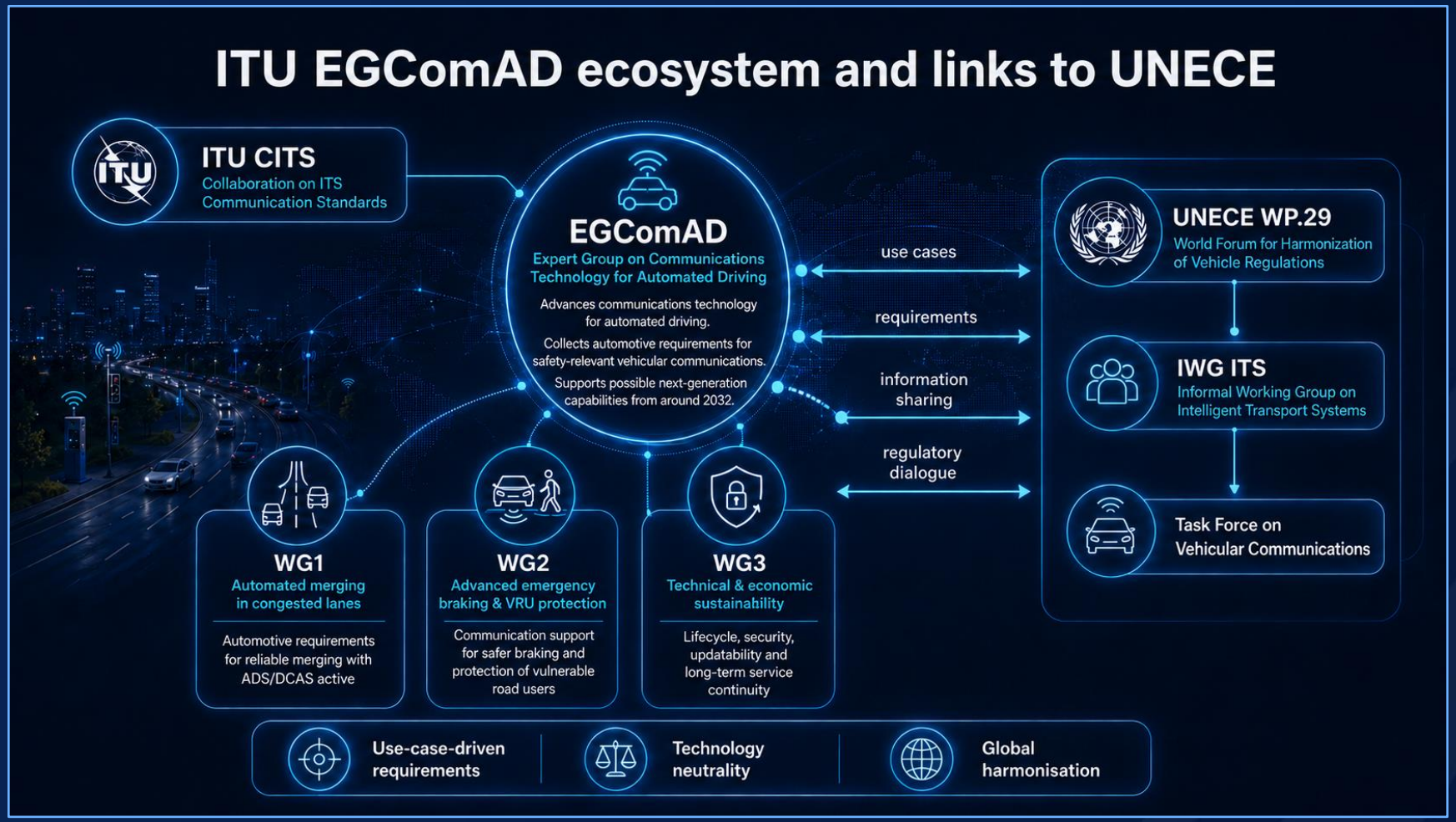
ITU EGComAD ecosystem and links to UNECE



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Thank you.

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