



Intelligent Transport Systems (ITS); Cooperative Adaptive Cruise Control (CACC); Pre-standardization study

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

Modal verbs terminology

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Introduction

The CACC application is an extension of the in-vehicle Adaptive Cruise Control (ACC) system. It enables further reduction of the time gap with preceding vehicles compared to the ACC system, thanks to Vehicular communications.

1 Scope

The present document describes the outputs of a pre-standardization study of the Cooperative Adaptive Cruise Control (CACC) application. It consists of:

- Definition of the CACC use cases;
- Definition of CACC architecture;
- Requirement analysis of the application and the communication systems;
- Recommendations on the standardization needs for the communication layers (including facilities layer, Networking & Transport layer and access layer) in support of the CACC application;
- Recommendation on the CACC application standardization.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] "G7 declaration on automated and connected driving" (09/2015).

NOTE: Also available at https://ec.europa.eu/commission/commissioners/2014-2019/bulc/announcements/g7-declaration-automated-and-connected-driving_en.

[i.2] ETSI EN 302 665 (V1.1.1): "Intelligent Transport Systems (ITS); Communications Architecture".

[i.3] SAE J3016: "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems".

[i.4] ETSI TS 101 539-3: "Intelligent Transport Systems (ITS); V2X Applications; Part 3: Longitudinal Collision Risk Warning (LCRW) application requirements specification".

[i.5] ETSI TS 101 539-2: "Intelligent Transport Systems (ITS); V2X Applications; Part 2: Intersection Collision Risk Warning (ICRW) application requirements specification".

[i.6] ETSI EN 302 637-2 (V1.4.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.7] ETSI EN 302 637-3 (V1.3.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[i.8] ISO 15622: "Intelligent Transport Systems - Adaptive Cruise Control Systems (ACC) - Performance requirements and test procedures".

[i.9] "Using Cooperative Adaptive Cruise Control (CACC) to Form High-Performance Vehicle Streams; Definitions, Literature Review and Operational Concept Alternatives".

NOTE: Available at: <https://escholarship.org/uc/item/3m89p611>.

[i.10] ETSI TS 103 301 (V1.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services".

[i.11] ETSI TS 102 894-1 (V1.1.1): "Intelligent Transport Systems (ITS); Users and applications requirements; Part 1: Facility layer structure, functional requirements and specifications".

[i.12] ISO/DIS/20035: "Intelligent Transport Systems - Cooperative Adaptive Cruise Control Systems (CACC) - Performance requirements and test procedures".

[i.13] ETSI TS 102 894-2 (V1.3.1): "Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary".

[i.14] Result of C-ITS Platform Phase II Release 1 (12/2017): "Security Policy & Governance Framework for Deployment and Operation of European Cooperative Intelligent Transport Systems (C-ITS)".

NOTE: Available at: https://ec.europa.eu/transport/sites/transport/files/c-its_security_policy_release_1.pdf.

[i.15] ETSI TS 103 097 (V1.3.1): "Intelligent Transport Systems (ITS); Security; Security header and certificate formats".

[i.16] AUTONET 2030 D3.2: "Specifications for the enhancement to existing LDM and cooperative communication protocol standards".

NOTE: Available at: <http://www.autonet2030.eu/wp-content/uploads/2015/02/D3.2-Specifications-cooperative-communication-protocol-standards-draft-for-approval.pdf>.

[i.17] DATEX II release 3.0.

NOTE: Available at: https://datex2.eu/support/getting_started.

[i.18] OCIT®-C: "Open Communication Interface for Road Traffic Control Systems - Center to Center".

NOTE: Available at: <https://www.ocit.org/en/ocit/interfaces/ocit-c/>.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

active CACC vehicle: CACC vehicle with CACC at active state

CACC: V2X capable in-vehicle driving assistance system that adjusts automatically the vehicle speed to keep a target time gap with target vehicle while keeping a minimum safety distance, making use of information communicated from other vehicles and/or from the roadside infrastructure

CACC application: application layer entity that implements the CACC functionalities and application logic

CACC pair: subject vehicle and its target vehicle

CACC string: two or more CACC pairs in sequence

NOTE: 1st active CACC vehicle is the target vehicle of the 2nd active CACC vehicle, and so forth.

CACC vehicle: vehicle equipped with the system in question

NOTE 1: A CACC vehicle may or may not activate CACC at a point in time.

NOTE 2: A CACC vehicle is V2X capable.

lead vehicle: first vehicle in the upstream end of CACC string or a CACC pair

NOTE 1: The lead vehicle may not be CACC vehicle.

NOTE 2: In a CACC pair, the lead vehicle and target vehicle may be identical.

NOTE 3: Lead vehicle of a CACC string is the target vehicle of the 1st active CACC vehicle.

measured time gap: time gap between a subject vehicle and its preceding vehicle, measured at one point in time

subject vehicle: CACC vehicle with the role to follow a target vehicle

target time gap: time gap targeted by the subject vehicle for CACC operation

target vehicle: V2X capable vehicle and counterpart of the subject vehicle for the CACC application

NOTE: The target vehicle is not necessarily a CACC vehicle.

time gap: time interval between when a preceding vehicle's rear end and a following vehicle's front end passes the same location on the road surface, assuming that the following vehicle speed remains constant

V2X capable: capable of transmitting and/or receiving facilities and application layer message (e.g. CAM) with other ITS-S using wireless communications

3.2 Symbols

For the purposes of the present document, the following symbols apply:

Δt_{min}	Minimum safety time gap
v_s	Instant speed of subject vehicle
v_t	Instant speed of TV
a_{sv}	Maximum deceleration of SV
Δt_{target}	Target time gap
Δt	Time gap between two vehicles

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACC	Adaptive Cruise Control
BTP	Basic Transport Protocol
CA	Cooperative Awareness
CACC	Cooperative ACC
CAM	Cooperative Awareness Message
CC	Cruise Control
DATEX II	DATA EXchange II
DATEX	DATA EXchange standard for exchanging traffic information
DCC	Decentralized Congestion Control
DE	Data Element
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
DF	Data Frame
GDPR	General Data Protection Regulation
GN	GeoNetworking
GN/BTP	GeoNetworking/Basic Transport Prototol
HMI	Human Machine Interface
HW/SW	Hardware/Software

I2V	Infrastructure to Vehicle
ITS	Intelligent Transport System
ITS-S	ITS Station
LDM	Local Dynamic Map
MAPEM	MAP (topology) Extended Message
OCIT-C	Open Communication InTerface for road traffic Control systems
OTA	Over-The-Air
PDU	Packet Data Unit
POTI	POsition and TIming
SAE	Society of Automotive Engineers
SAM	Service Advertisement Message
SPATEM	Signal Phase And Timing Extended Message
SRM	Signal Request Message
SSM	Signal Status Message
SSP	Service Specific Permission
SV	Subject Vehicle
SW	SoftWare
TPEG	Transport Protocol Experts Group
TS	Technical Specification
TV	Target Vehicle
UC	Use Case
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VDP	Vehicle Data Provider

4 CACC introduction

4.1 Background

In September 2015, the Transport Ministers of the G7 States and the European Commissioner for Transport agreed on a declaration on automated and connected driving [i.1] with the objective of making a significant contribution towards increasing road safety and improved mobility worldwide. The Declaration underlined the need to take appropriate steps to establish a harmonised regulatory framework. In EU, deploying vehicles without a human driver is an option only for restricted and well-defined areas. Several Member States already allow or have announced the adoption of legal acts to make the testing of automated vehicles legal, e.g. on an approved test route or in an urban environment, where the vehicle, the infrastructure and the environment are controlled.

The main motivation of CACC is to further reduce the time gap between vehicles compared to Adaptive Cruise Control (ACC) system as defined in [i.8] and to improve the response to the speed variation of the target vehicle. This would bring benefits to driver, road operator and potentially to society.

For the driver, the main benefit of CACC is related to gain the feeling of comfort, with a reduced and automatically maintained (but safe) time gap, and to the better response to the speed variation of the target vehicle. In addition, reduction of fuel consumption may be gained, thanks to the reduction of traffic jam.

For road operators, the main benefit of CACC may be related to increased road capacity and traffic efficiency. Study has shown that highway lane capacity improvement may already be observed even with low penetration rate [i.9].

The social benefits of CACC may be related to increased road safety, reduced traffic jam and or environmental benefits. Even though safety is not the primary goal of CACC, CACC can make ACC more attractive and convenient to drivers by providing behaviour that is more responsive to preceding vehicle speed changes, that gives an enhanced sense of safety because of its quicker response [i.9].

Nevertheless, special traffic management means may be needed, to optimize the traffic benefits of CACC on highway or at urban environment. For example, some simulation studies have shown CACC may even bring negative effects on lane capacity or even create traffic jams, until appropriate infrastructure support is provided. Example infrastructure support may be specific lanes assigned for CACC pair and CACC string, where road side ITS-S may provide optimized time gap and driving speed for CACC vehicles for maximizing lane capacity and traffic flow fluency.

4.2 CACC definition

CACC is an in-vehicle driving assistance system that adjusts automatically the vehicle speed to keep a target time gap Δt_{target} with a target vehicle (TV) while keeping a minimum safety distance with it. CACC makes use of data received from other vehicle ITS-Ss and/or from road side ITS-Ss via ITS network. The CACC includes at least one ITS-S application (denoted as CACC application) that implements the application logic with the services provided by the lower layers (Facilities, Networking & Transport layer, Access layer) as specified in ETSI EN 302 665 [i.2], and a set of hardware components. The CACC application processes data received from other ITS-Ss and/or from on board sensors, automatically determines vehicle speed and acceleration, and accordingly transmits control commands to longitudinal control systems (e.g. brake, accelerator). In addition, the CACC application may be operating simultaneously with other in-vehicle assistance systems or with other ITS-S applications such as pre-crash system, lateral control system, etc. CACC is connected to the in-vehicle network and has access to in-vehicle sensor data. The CACC can send control commands to acceleration/deceleration systems.

Multiple active CACC vehicles may follow each other, to form a vehicle group, denoted as CACC string in the present document. A CACC string operational environment may change dynamically e.g. a CACC string may be divided into two groups. A CACC string may be combined with another CACC string to form a new CACC string, or a CACC string may be dismissed when all vehicles leave the string.

CACC may be operated in expressway or in urban/suburban environment.

Figure 1 illustrates an example functional overview of the CACC. The dotted red rectangle illustrates the focuses of the present pre-standardization study scope. In general, the implementation of the hardware components is at the discretion of implementers. Nevertheless, the requirements defined in the present document may impact on the HW/SW implementation, for example, the compliance to the communication protocol standard is required to be considered in the development of the communication systems.

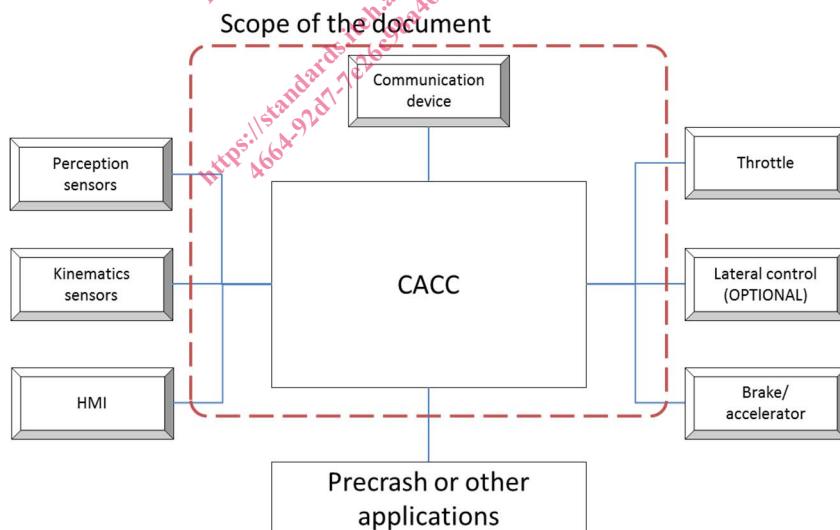


Figure 1: Scope of the document

4.3 CACC target time gap

CACC target time gap Δt_{target} is the time gap set by CACC to follow a Target Vehicle (TV). The CACC adjusts the acceleration, speed and/or brake to maintain the time gap Δt with TV to the Δt_{target} . Time gap is the time interval between when a preceding vehicle's rear end and a following vehicle's front end passes the same location on the road surface, assuming that the following vehicle's speed remains constant. The CACC target time gap is illustrated in Figure 2.

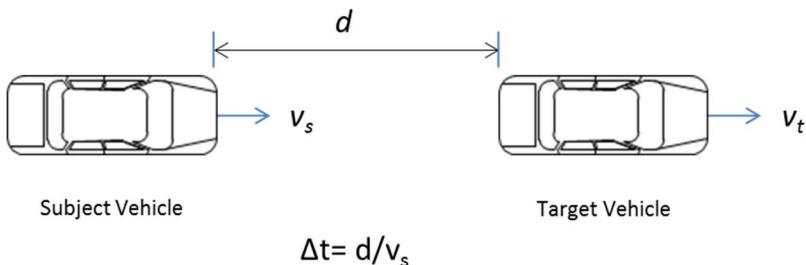


Figure 2: CACC target time gap

The Δt_{target} may be set according to different rules. In one possible setting, the Δt_{target} is proportional to vehicle speed when the vehicle speed is equal or higher than a predefined value. When v_s is below that value, a minimum distance d_{min} is required to be maintained. This setting rule is specified in ISO/DIS/20035 [i.12].

NOTE: In this setting rule, it is up to driver to ensure that the safety distance with TV is kept in order to avoid potential collision risk.

In another possible setting, a minimum safety time gap is required to be maintained by CACC Δt_{min} , this minimum safety time gap should be equal or higher than the time required for collision avoidance. When the Δt falls below Δt_{min} , the CACC application may be taken over by collision risk warning applications (automatic or manual), for example the Longitudinal Collision Risk Warning [i.4] or Intersection Collision Risk warning applications [i.5].

$$\Delta t_{min} = |v_s - v_t| / a_{sv}$$

Where:

- Δt_{min} denotes minimum safety time gap.
- v_s denotes instant speed of SV.
- v_t denotes instant speed of TV.
- a_{sv} denotes maximum deceleration of SV.

4.4 CACC and automation levels

Depending on implementation strategy, the CACC system may be used to support different automated driving modes (automation levels). In the scope of the present document, the following automation levels are used, as defined in SAE J3016 [i.3]:

- Automation level 0 as defined in SAE J3016 [i.3]. This level corresponds to the manual driving mode. CACC does not participate in this automation level.
- Automation Level 1: as defined in SAE J3016 [i.3]. The level 1 system assists driver for the acceleration/deceleration control in specific driving situations to maintain the target time gap with TV. The driver triggers, configures the Δt_{target} , terminates the CACC via specific Human Machine Interface (HMI) and when necessary, takes over the acceleration/deceleration control. A standalone CACC system is a level 1 system.
- Automation level 2: as defined in SAE J3016 [i.3]. The CACC is operating simultaneously with lateral control assistance systems such as lane keeping system, lane change assistance system. In this automation level, the CACC is triggered, configured and terminated by the human driver. Optionally, and thanks to the interaction between longitudinal and lateral assistance systems, the CACC may be temporally adjusted to support other driving assistance system e.g. the CACC configuration may be adjusted to support the automatic lane change.