Project Specific Technical Specification

Transport and Main Roads
PSTS017 BoQ Use Case Specification – Back-of-Queue

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Queensland Government

Document control sheet

Contact for enquiries and proposed changes

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Version history

Version no.	Owner	Date	Nature of amendment
1.0	David Alderson	29/06/2018	Tender Issue
1.1	Kathy Mosley/ David Alderson	18/03/2019	Update to REQ_PSTS017_018
1.2	David Alderson	06/07/2019	Updates to match learnings from implementation
1.3	Zinah Tam	27/07/2020	Updated Table 7.2 to match final incorporation of HUET recommendations
1.4	Zinah Tam	14/09/2020	Updated Table 7.2 to match release 25.2
2.0	Nicholas Brook	28/01/2021	
2.1	Jian Qin	07/10/2021	System Architecture drawing update

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Contents

1 Introduction

The Back of Queue (BoQ) use case specification is intended to provide future use case developers (including V-ITS-S vendors) with details of the Ipswich Connected Vehicle Pilot (ICVP) implementation as a guide. As use cases are expected to fall within the remit of original equipment manufacturers (car, application or device developers) it has been adapted from a prescriptive set of requirements for the pilot, to an example of potential operation within any future Cooperative ITS eco-systems. These are also not to be used directly as a specification for other Transport and Main Roads projects or integration, as they will either be adapted to be project specific or ratified and released as a formal Department Specification.

This specification includes:

- Objectives, general operation and applicable scenarios;
- System components and data flows;
- Life cycles;
- High level HMI requirements;
- Data and message examples; and
- Data definitions.

2 Definition of terms

Table 2.1 – Acronyms

Acronym	Term
ASN.1	Abstract Syntax Notation One
BoQ	Back of queue
C-ITS	Cooperative intelligent transport systems
C-ITS-F	Central ITS facility
DENM	Decentralised environmental notification message (EU)
DWT	Driver Warning Trigger
ETSI	European Telecommunications Standards Institute
FOT	Field operational test
HMI	Human machine interface
ITS	Intelligent transport systems
PDU	Packet Data Unit
PSTS	Project Specific Technical Specification
QD	Queue Detection
R-ITS-S	Roadside ITS station
RTK	Real Time Kinematic
SCMS	Security credential management system
TSC	Traffic Signal Controller
TTA	Time to Action
TTE	Time to Event
UPER	Unaligned Packed Encoding Rules
V-ITS-S	Vehicle ITS station
XML	eXtensible Markup Language

Table 2.2 – Definitions

Acronym/Term	Term Description
3G/4G	Cellular wireless network provided through a telecommunications company. 3G is the 3rd generation data network, 4G the fourth and LTE stands for Long Term Evolution.
AUSCORS	Australian Cross Origin Resource Sharing - the way that the NTRIP data is broadcasted by Geoscience Australia.
FOT	Field Operational Test – the period when the in-vehicle C-ITS systems are operational and logging data
HMI Presentation Manager	Function of the V-ITS-S that arbitrates the information presentation requests to the HMI device
Monitoring system	Sub-system of the C-ITS-F that monitors the operation of the C-ITS Pilot system
Use case warning	A warning presented by the HMI when use-case applications are trigged

3 Reference documents

Table 3.1 – Referenced documents – External

Document ID	Document Name / Description
ETSI TS 101 539-3 v1.1.1 (2013-11)	Intelligent Transport Systems (ITS); V2X Applications;Longitudinal Collision Warning (LCRW) application requirements specification
ETSI EN 302 637-3 V1.2.2 (2014-11)	Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service

Table 3.2 – Referenced documents – Internal

Document ID	Document Name / Description
PSTS002	V-ITS-S Equipment
PSTS003	HMI Equipment
PSTS006	Data Entity Catalogue
PSTS007	C-ITS Station Protocol Specification

4 Quality system requirements

4.1 Test Acceptance Criteria

For ICVP the V-ITS-S Vendor demonstrated compliance to this specification in accordance with the test acceptance phases defined in the *V-ITS-S Specification PSTS002*.

For each requirement, the selected test plan/s included criteria that clearly defines how each requirement is met to suitably integrate within the ICVP systems. Test plans at a minimum included; consideration of the primary and alternate scenario equivalents identified in this specification. Some circumstances including testing of other scenarios identified by the V-ITS-S Vendor or Principal as appropriate to prove; device, use case or system implementation.

Sample DENMs are provided in the sample data pack in the following encoding formats:

a. UPER (encoded)

b. JSON (decoded)

The data pack also contains the ASN.1 value notation that were used for each use case.

5 Overview

The Back of Queue (BoQ) use case provides the driver of a cooperative vehicle a warning on the approach to a downstream traffic queue early enough to react safely prior to reaching the conflict point. The BoQ use case is provided as a DENM from the C-ITS-F including relevant queue data.

The information for the DENM will be sourced from STREAMS Traffic Management Platform's Queue Detection (QD) algorithm. The algorithm analyses motorway vehicle detectors, when a speed and occupancy threshold are met, it creates a QD object including key information (queue length, head location, tail location, growth rate). This information is collated from the STREAMS Gateway API before being created into C-ITS messages in the C-ITS-F for distribution to vehicles.

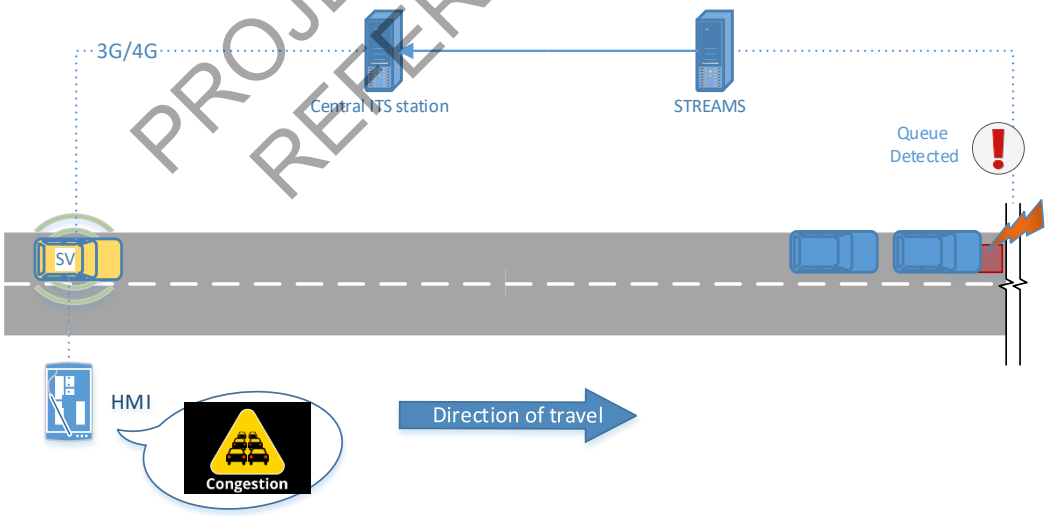


Figure 5.1 – BoQ operation

Requirement: The BoQ application shall manage and display back of queue warnings to the driver.

Requirement: The BOQ application shall store and monitor current geo-tile BoQ for up to 50 BoQ events at a given time.

Requirement: The BoQ application shall be capable of handling up to 3 overlapping BoQ simultaneously.

5.1.1 Primary Scenario

In the primary scenario for BoQ (refer to Figure 5.2) the vehicle approaches the back of queue, its position (including lateral offsets) overlap the trace (and within the relevance distance) and in the correct direction (lane does not matter). An informative HMI warning is provided to the driver prior to reaching the queue to give the driver enhanced situational awareness.

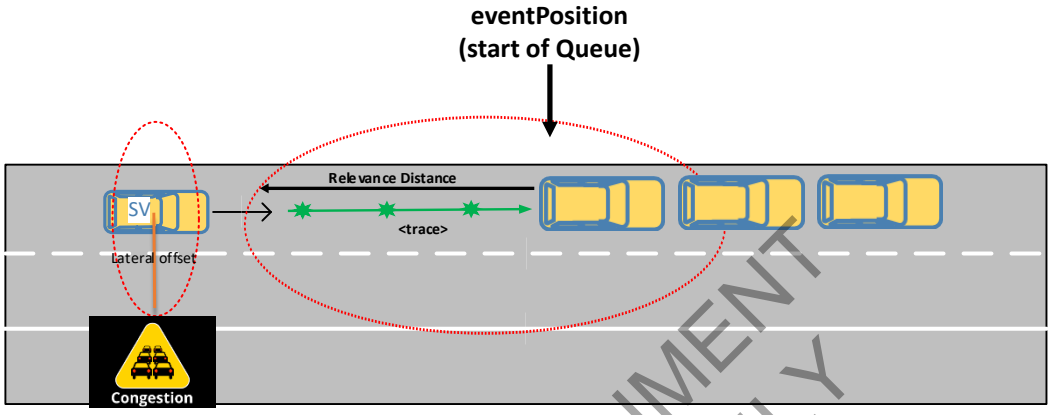
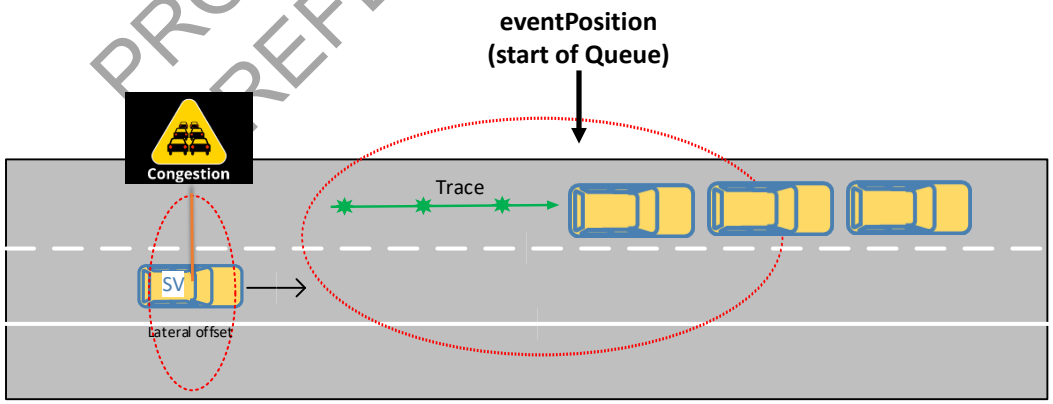


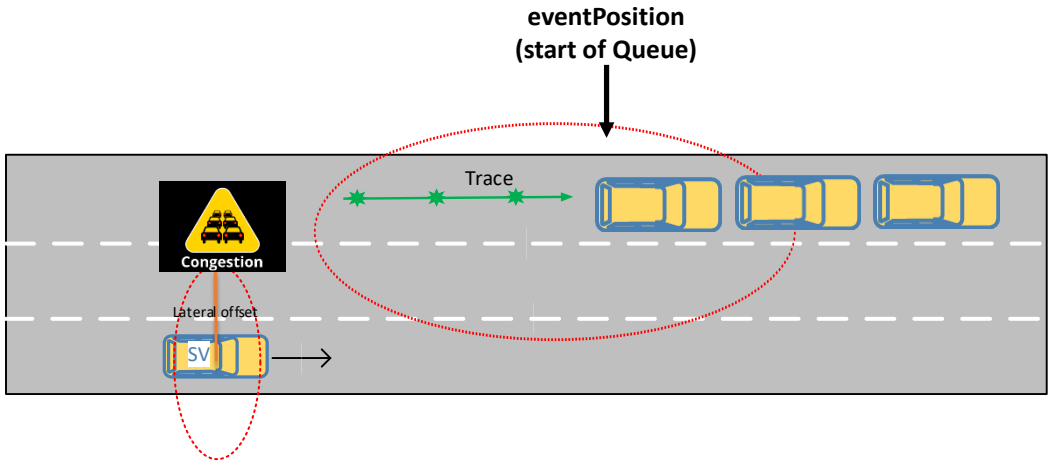
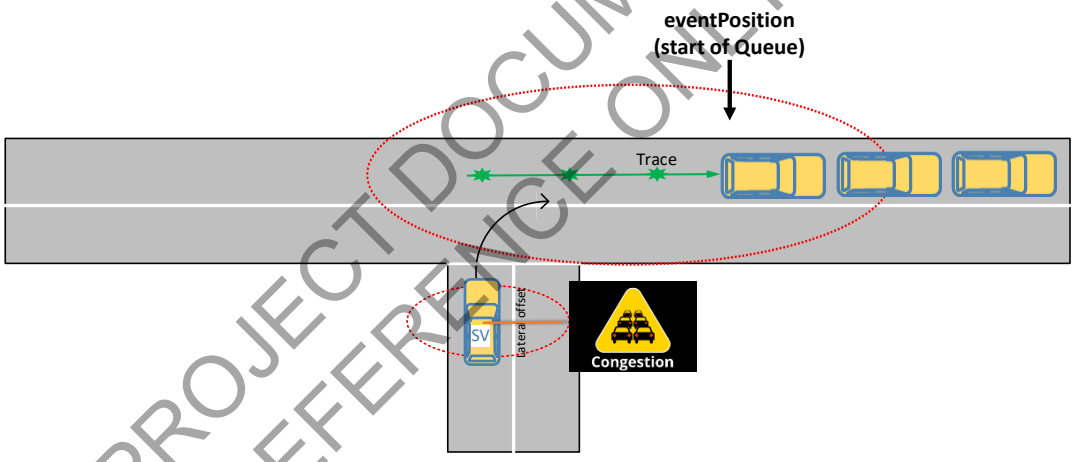
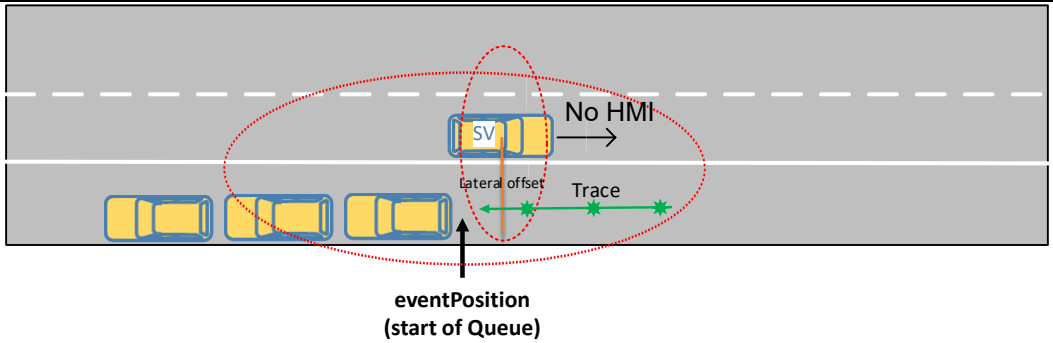
Figure 5.2 – Primary Scenario

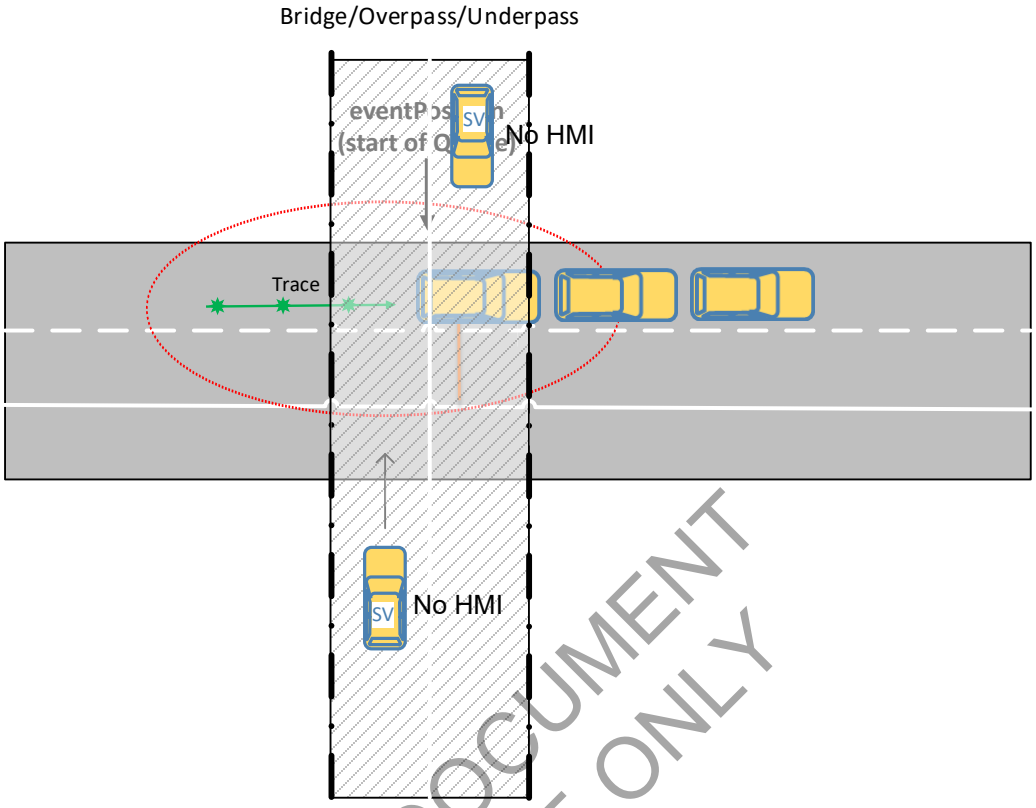
5.1.2 Scenario Equivalents

The following table describes the same primary scenario above but with several variants and the expected outcome.

Table 5.1 – Scenario Equivalents

Variant	Visualisation and Comment
Adjacent lanes or wide lanes where lateral offset and trace intersect.	 HMI Warning: Yes

Variant	Visualisation and Comment
Adjacent lanes or wide lanes where lateral offset and trace do not intersect.	 HMI Warning: Yes, the queue detection algorithm in STREAMS is not lane level accurate, therefore the C-ITS message or use by a vehicle station be also cannot be. The queue object and trace are positioned by the C-ITS-F spatial service as the centre of the carriageway.
Vehicle is entering from side road	 HMI Warning: Yes, but after the vehicle is determined to be on a trace or event history of the back of queue event
Vehicle is driving in the opposite direction to queue	 HMI Warning: No, the heading is in the wrong direction for the application to assess the trace as relevant.

Variant	Visualisation and Comment
Vehicle is driving on a bridge above the queue (in a different vertical plane)	 HMI Warning: No Comment: This scenario should not display a HMI warning because the vehicle is not following the same path as the back of queue DENM (due to heading and the elevation).

5.1.3 Vehicle Offsets

A lateral offset (distance from the centre of the vehicle) provides additional tolerance in vehicle width to coincide with the trace of the BoQ DENM. This allowance is required for BoQ as the accuracy of input data does not allow the DENM to be lane level specific.

Requirement: The BoQ application shall apply a configurable lateral offset (*lateralOffset*) when calculating the vehicle position to the trace for the BoQ use case.

6 System Components

The BoQ use case is an I2V application and as a result the primary interface is between the C-ITS-F and the V-ITS-S (and HMI). Data is input into the system using the STREAMS.

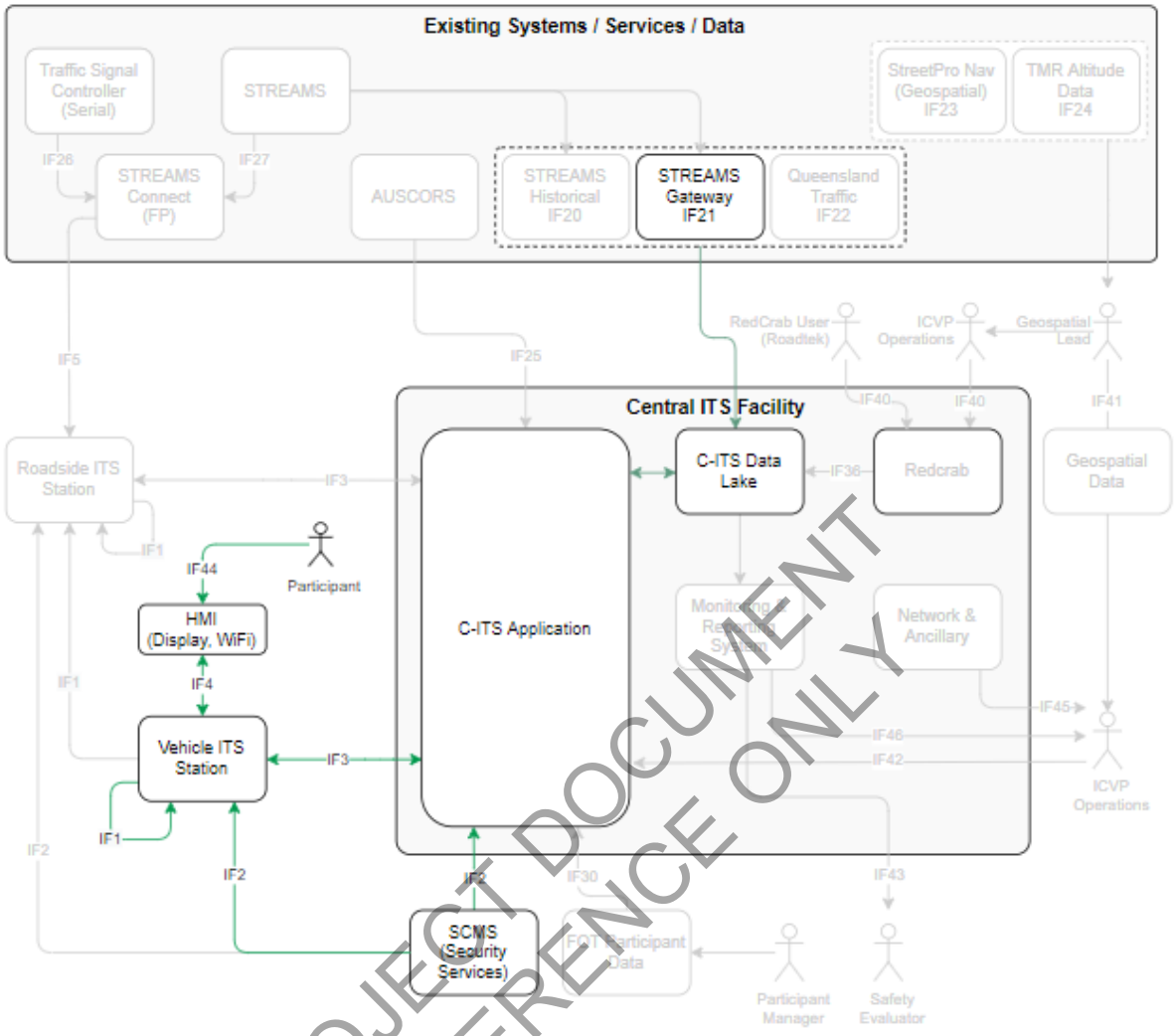


Figure 6.1 – System Architecture

The table below describes the system components that interact for the overall operation of the BOQ application.

Table 6.1 – System Component Summary

Component	Role	Requirement	Detailed component lifecycle
V-ITS-S	Event Processor	The BoQ use case application is performed in the V-ITS-S.	The process for managing the BoQ use case is defined in section 7.1
HMI	Driver Interface	HMI must be on and able to interact with the V-ITS-S for display and status	HMI warnings are defined in section 7.3
STREAMS	Data source	Manages queues on freeways	Not applicable. Managed by C-ITS-F

Component	Role	Requirement	Detailed component lifecycle
C-ITS-F	Messaging and Monitoring	Manages queue updates from STREAMS and provides current queue events to V-ITS-S. Interface for monitoring and use case data logging.	Defined in *C-ITS-S Station Protocol Specification PSTS007*
SCMS	Enabler	Provide secure communications	Defined in *V-ITS-S Specification PSTS002*
AUSCORS	Positioning Augmentation	Provides data to the V-ITS-S through the C-ITS-F that allows greater positioning accuracy for the operation of the use case	Defined in *V-ITS-S Specification PSTS002*
FOT	Evaluation	Evaluation of use case log data.	Not applicable. Managed by C-ITS-F

Requirement: The V-ITS-S shall meet the requirements of *V-ITS-S Specification PSTS002* as a basis for enabling the BoQ use case operation. Communications between components using 3G/4G are detailed in *V-ITS-S Specification PSTS002* including communications interface, security management and protocols to enable the data transfers described in Figure 6.2.

Requirement: The HMI shall meet the requirements of *HMI Specification PSTS003* as a basis for enabling the BoQ use case speed updates.

6.1 Typical Process Flow

The process flow for the BoQ event is shown in Figure 6.2. This describes the normal process for the event through the relevant system components. The component lifecycles in section 7 describe the detailed creation, management, validation and completion states of the use case (Note: FOT uses an independent process flow to the C-ITS-F and are therefore not included in this use case process flow). The second stage of Figure 6.2 in which the V-ITS-S retrieves queue information from the C-ITS-F returns BoQ for the requested geo-tile.

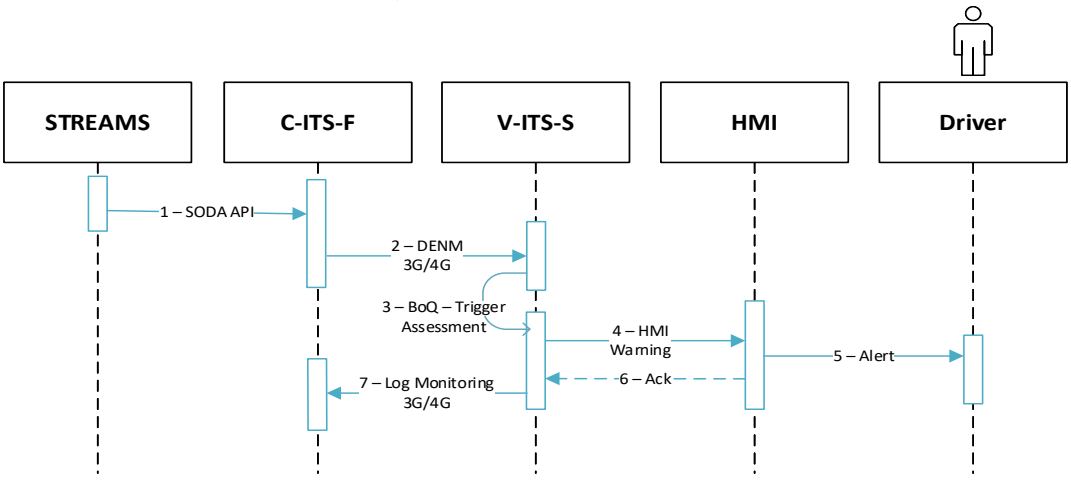


Figure 6.2 - Typical BOQ application flow

7 Lifecycles

The BoQ event is generated in the V-ITS-S application. Therefore, the event life cycle for this use case matches the V-ITS-S application lifecycle.

7.1 V-ITS-S Application Lifecycle

Figure 7.1 shows a process flow expected from the application within the V-ITS-S to receive BoQ DENMs and determine use case behaviour.

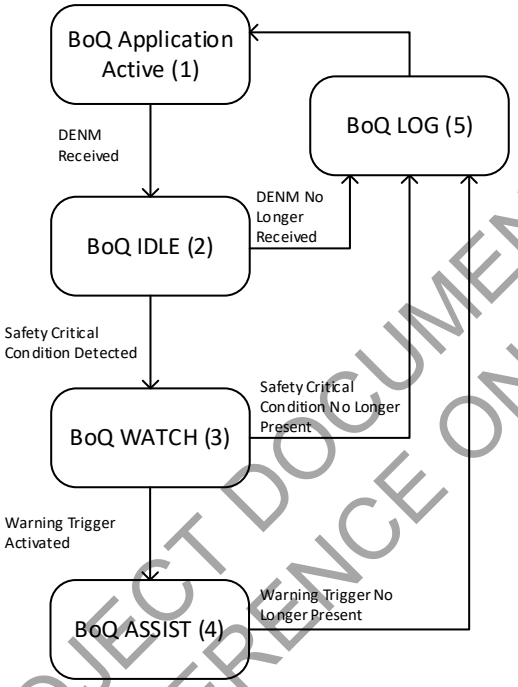


Figure 7.1 – V-ITS-S Lifecycle (modified from ETSI 101 539-03:2013)

Requirement: The V-ITS-S shall apply the lifecycle states and transitions in the BoQ application (or proven equivalent operation). A critical failure (as defined by the Contractor) in any state or transition shall cause the application to attempt to restart from state (1) to continue normal operation.

Requirement: The BoQ application shall start up if enabled and request all BoQ DENM for the current geo-tile from 3G/4G (see *ucBoqEnabled* in *V-ITS-S Specification PSTS002* for application enabling and disabling). *(State 1)*

Requirement: While the V-ITS-S is powered on the BoQ application shall ensure that it receives updates to the BoQ DENM by maintaining a subscription to the message topics *(see C-ITS Station Protocol PSTS007).*

Requirement: The BoQ application shall receive and maintain the DENM for the current geo-tile and update with new DENM when entering new geo-tiles. DENM received (see *V-ITS-S Specification PSTS002* for requirements of geo-tile and C-ITS-F data transfer) *(Transition 1 to 2)*

Requirement: BoQ application shall compare the vehicle metrics (such as speed and location) to the queue to determine if the safety critical conditions are met. In order to meet the safety critical conditions, the vehicle shall be: *(State 2)*

1. Travelling between the minimum (*speedMin*) and maximum (*speedMax*) speed, and
2. Within the *relevanceDistance* defined in the DENM, and
3. Following the *trace* (based on lateral offset defined in section 5.1.3) in the same direction as an active DENM.

Requirement: If the *validityDuration* in the DENM has expired or is cancelled by the C-ITS-F, the BoQ application shall consider the queue as no longer present. *(Transition 2 to 5)*

Requirement: To meet the safety critical conditions, the vehicle shall be: *(Transition 2 to 3)*

1. Travelling between the minimum (*speedMin*) and maximum (*speedmax*) speed; and
2. Within the *relevanceDistance* defined in the DENM; and
3. Following the *trace* (based on lateral offset defined in section 5.1.3) in the same direction as an active DENM.

Requirement: BoQ application shall assess the collision risk as defined in section 7.2. *(State 3)*

Requirement: BoQ application shall determine that the vehicle safety critical conditions are no longer met if: *(Transition 3 to 5)*

1. The vehicle reduces below the minimum clearance speed (*speedClear*); or
2. The vehicle departs from the r*elevanceDistance* in DENM; or
3. The vehicle departs from the *trace* (based on lateral offset defined in section 5.1.3); or
4. A DENM is cancelled or validity duration is over (with no update received) by the C-ITS-F and received by the V-ITS-S.

Requirement: A collision risk shall be active if action is required within the safety thresholds as defined in section 7.2 *(Transition 3 to 4)*

Requirement: The BoQ application shall request the appropriate HMI warning as defined in section 6.3 to the HMI Presentation Manager detailed in *V-ITS-S Specification PSTS002*[1]. The BoQ application shall monitor acknowledgements and the status of the HMI while the display request is active. *(State 4)*

Requirement: BoQ HMI warning request shall be cleared if: *(Transition 4 to 5)*

1. The vehicle safety critical conditions are no longer met (see transition 3 to 5 above)

[1] The HMI Presentation Manager provides a single point of control for managing, prioritizing and logging all driver alerts including all use case warnings, speed limits and system status.

Requirement: The BoQ application shall log event information in accordance with *V-ITS-S Specification PSTS002* and send to C-ITS-F on 3G/4G. *(State 5)*

Requirement: The BoQ application shall confirm the event is logged and event completed *(Transition 5 to 1)*

7.2 Warning Trigger

When the vehicle enters the relevance distance and the trace of the BoQ event, the vehicle must determine whether there is a collision risk based on the Time-To-Event (TTE) between the vehicles and the minimum driver warning triggering time as shown in Figure 7.2.

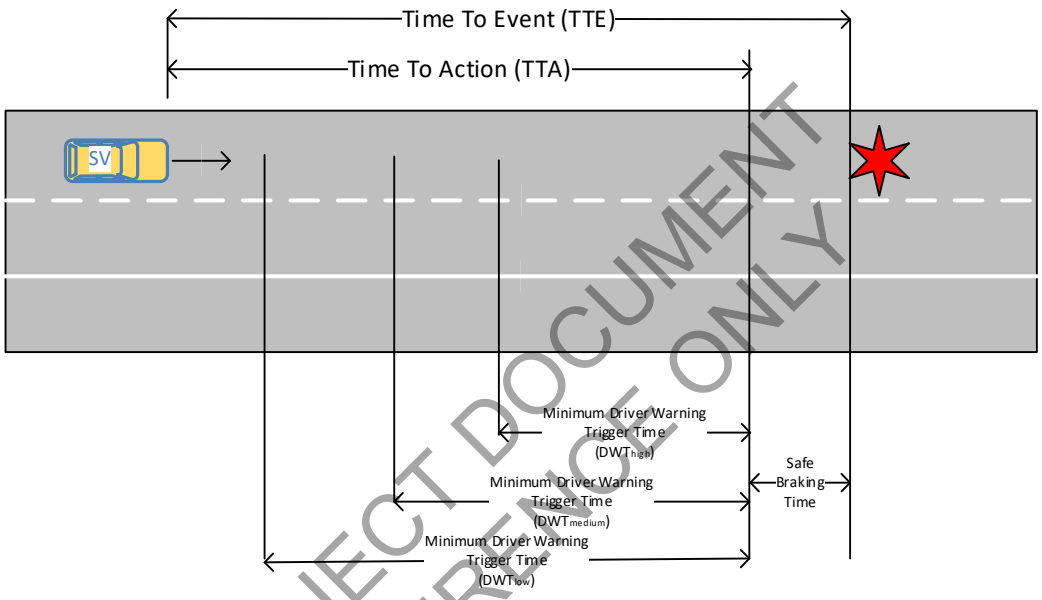


Figure 7.2 – Minimum Warning Trigger Time

Based on the TTA, the trigger is determined based on the graph in Figure 7.3.

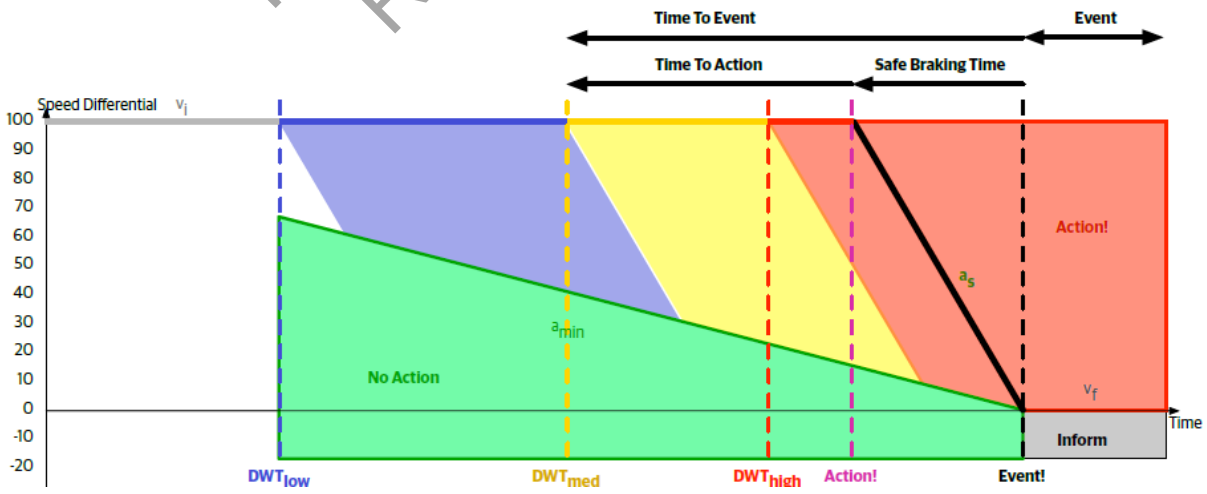


Figure 7.3 – Determining triggers from TTA

Requirement: Distance (d_{V_Q} in metres) to the back of the queue shall be calculated based on the DENM event point and vehicle location.

Requirement: While the application is in BoQ WATCH, it shall assess safe braking time, safe braking distance and TTA based on the following calculations:

$$\text{Safe Braking Time} = t_{safe} = (v_f - v_i) / a_{safe}$$

$$\text{Safe Braking Distance} = d_{safe} = v_i * t_{safe} + ½ * a_{safe} * t_{safe} * t_{safe}$$

$$\text{Time-To-Action} = \text{TTA} = (d_{V\_Q} - d_{safe}) / v_i$$

Where:

v_i = Current Speed

v_f = Speed required to reach for an BoQ event (*eventSpeed* in DENM)

a_{safe} = Safe braking deceleration speed (*decelerationSafe*)

Requirement: The BoQ application shall consider the TTA as not applicable (no warning required) if:

1. a significant amount of time for braking is available; and
2. a significant distance for braking is available; and
3. A TTA based on the following calculations:

$$\text{No Action Time} = t_{no\_action} = (v_f - v_i) / a_{min}$$

$$\text{No Action Distance} = d_{no\_action} = v_i * t_{no\_action} + ½ * a_{min} * t_{no\_action} * t_{no\_action}$$

$$\text{Time-To-Action at minimum braking} = \text{TTA}_{min} = (d_{V\_Q} - d_{no\_action}) / v_i$$

Where:

v_i = Current Speed

v_f = Speed required to reach for an BoQ event (*eventSpeed* in DENM)

a_{min} = Minimal braking deceleration speed (*decelerationMin*)

Requirement: Based on the TTA and TTA_{min} calculations, the V-ITS-S application shall associate a HMI warning identifier.

Table 7.1 – Driver Warning Trigger Time to HMI Warning

Collision Risk	Description	HMI Warning ID
TTA < *thresholdMedium*	Safety awareness required	BOQ_MEDIUM
thresholdMedium < TTA < *thresholdLow*	Comfort warning required	BOQ_LOW
TTA > *thresholdLow*	No action required	No HMI change
TTA_{min} > 0	No action required	No HMI change

Note: High warning level may be required if accuracy of the use case input is improved.

7.3 HMI Warning

The HMI warning provides information in the vehicle that allows the driver to take suitable evasive action. The HMI warning is based on the trigger calculations and the resulting collision risk. The library of BoQ use case HMI warnings includes the collision risk stages and an associated image/sound.

Requirement: The HMI shall display the image and play the audio sound based on the HMI warning requested from the V-ITS-S and information presented in Table 7.2. The HMI warning shall display in accordance with *HMI Specification PSTS003*. The V-ITS-S and HMI shall provide image and audio sound configuration updates based on the HMI Warning ID.

Table 7.2 – HMI Warning Lookup

HMI Warning ID[1]	Description	Image	Audible Sound
BOQ_LOW	Comfort warning	None[2]	None
BOQ_MEDIUM	Safety warning		None

Notes:

1. High warning level may be required if accuracy of the use case input is improved.

2. The final HMI display for ICVP was optimised for simplicity of participants as such not all possible warning escalations were used. However, this does not form a recommendation for future use or TMR expectations of industry. It would be expected future developers would consider integration into existing systems to best suit users' expectations and understanding.

7.4 Continuity

Requirement: The HMI warning shall remain valid while the V-ITS-S preconditions and trigger conditions remain valid for the BoQ DENM. If the vehicle receives a new BoQ DENM with the same identifier, the trigger and display conditions shall be reassessed against the new parameters in the DENM in accordance with the V-ITS-S application lifecycle.

Requirement: On completion of the BoQ HMI warning, the HMI shall return to any lower priority use case HMI warning currently active (if no other HMI warnings are active, the HMI shall return to the default state as defined in *HMI Specification PSTS003*).

8 Key Configurable Parameters

Requirement: The following key configurable parameters shall be configurable from the C-ITS-F in accordance with *V-ITS-S Specification PSTS002*. These parameters shall be used through the use case to allow adjustments to the operation and timing.

Table 8.1 – Key Configurable Parameters

Reference Clause	Description	Unit	Factory Default	Final used*	Min	Max	Device(s), systems affected
5.1.3	*lateralOffset*	cm	600	1200	0	1000	V-ITS-S
7.1	*speedMin*	km/h	20	70	0	200	V-ITS-S
7.1	*speedmax*	km/h	130	130	0	200	V-ITS-S
7.1	*speedClear*	km/h	0	40	0	200	V-ITS-S
7.2	*decelerationSafe*	0.1m/s/s	48	48	0	100	V-ITS-S
7.2	*decelerationMin*	0.1m/s/s	8	1 (full trace)	0	100	V-ITS-S
7.2	*thresholdHigh*	ds	30	1 (off)	0	250	V-ITS-S
7.2	*thresholdMedium*	ds	100	250	0	250	V-ITS-S
0	Images and Audio per HMI Warning ID		N/A				V-ITS-S and HMI

Note: a value of 0 disables the function associated with the parameter.

***Optimisation note:** The above warning logic was used to be consistent with other similar use cases, including the same default configurable variables, however it was determined that this resulted in the use case presenting warnings too late to add value. The values were optimised to effectively warn as soon as the vehicle was on the trace rather than concerning deceleration profiles of vehicles, whilst cruder it resulted in more suitable warnings for this use case. Given the high speed environment BoQ operates, the location and environment of frequent queues, and the existing managed motorways ITS, vehicles were already slowing well before the warning was provided, hence acting as a mere reminder than pre-emptive and preventative warning.

9 Data Definitions

The DENM structure in Figure 9.1 describes the overview of the BoQ message which is subsequently detailed in data element level in the *Data Entity Catalogue PSTS006*. The message structure identifies the following data components:

1. ITS PDU container
2. Message set
3. Data frame
4. Sequence of data frame
5. Data element
6. Short listed CAVI DENM data attribute but not applicable to BoQ UC

Requirement: The BoQ application shall use DENM data elements in accordance with the *Data Entity Catalogue PSTS006*.

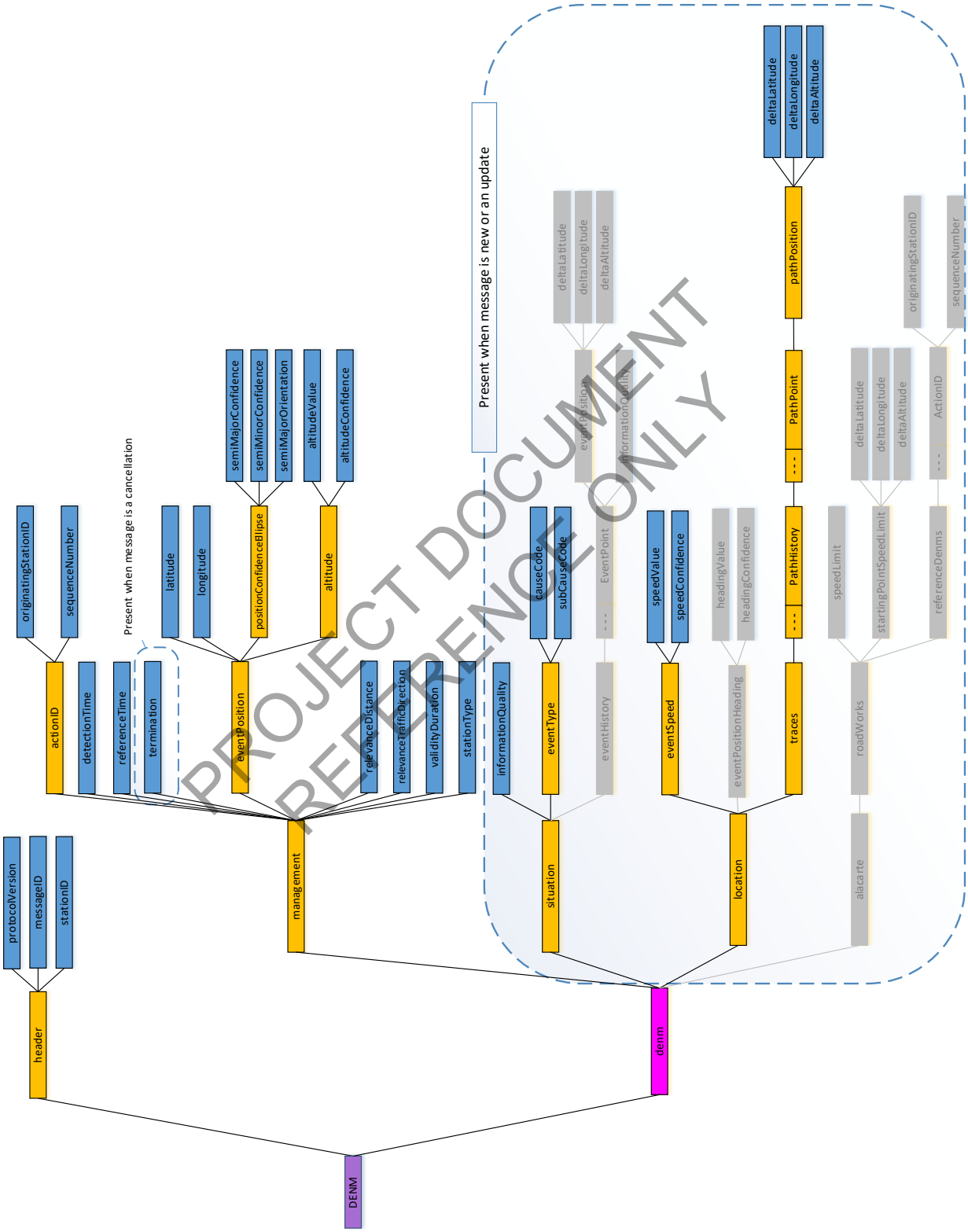


Figure 9.1- BoQ Message Structure