RAIDER

Generic Specifications for Incident Detection Systems

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Executive Summary

RAIDER (Realising Advanced Incident Detection on European Roads) is a research project funded within the framework of ERA NET ROAD by the National Road Administrations of Belgium, Switzerland, Germany, Netherlands, Norway and United Kingdom. The project investigates how to improve incident detection systems by incorporating new technologies for roadside systems and utilizing in-vehicle systems and nomadic devices. Improvements in incident detection are expressed in terms of detection quality and the estimated costs and benefits of the detection systems. The project, which began in November 2011 and runs to July 2013 is being carried out by a consortium comprising TNO from the Netherlands, AIT from Austria, TRL from the UK and FEHRL based in Belgium.

Incident detection is an essential capability for Road Authorities to manage their road networks and adequately respond to incidents. Issues with the quality of detection, such as a high false alarm rate, delays in detection, or inaccurate location of incidents, directly impact their operations. Significant investments may be required to improve the detection quality with additional roadside detection systems. At the same time, new developments in road side systems, nomadic devices and in-vehicle systems, and in third party services, may provide solutions that improve both incident detection quality and reduce the costs for National Road Authorities.

The first phase of the project aimed to define the user needs and requirements for incident detection systems of Road Authorities as well as their experiences on operational issues and products [1]. On the basis of the stakeholder consultation the following incident types are considered for motorway and secondary roads:

1. Accidents
2. Extraordinary congestion
3. Vehicle breakdown (including vehicle fire)

The main objective of RAIDER is to develop generic specifications for incorporating new technologies for incident detection. The detection performance and costs of new technologies are considered in several use cases.

The most relevant new technologies considered are eCall, cooperative systems, and nomadic devices, and in addition new road side detection technologies are considered for tracking vehicles and for travel time estimation. Detection performance is characterized in terms of detection rate, detection accuracy, detection delay, and false alarm rate. Detection performance is specified in a generic way, e.g. in terms of penetration rate or detector spacing and coverage. Set up, maintenance and operation costs are considered for setting up a new system, or upgrading or retrofitting existing systems. A Technology Library with fact sheets for the technologies considered is provided for reference in Annex 1.

Existing situations of Road Authorities are characterized in use cases. A use case defines the current situation in terms of the road network, traffic volume and existing detection systems. Scenarios are defined to improve the existing situation of a use case for a specific incident type. Section 6 contains the most relevant use cases and scenarios that have been considered in detail as and exemplifies how the detection performance improvements and costs can be considered for alternative system configurations of new technologies in the most relevant Use Cases:

- Motorway without a hard shoulder, high traffic volume and standard road side equipment,
- Motorway with a hard shoulder, high traffic volume and an existing tolling system,
- Motorway with a hard shoulder, low traffic volume and no existing road side system,
- Secondary roads with high traffic volume and no existing road side system.
- Secondary roads with low traffic volume and no existing road side system.

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Definitions

Term	Definitions
Incident	Any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand, such as traffic crashes, disabled vehicles, spilled cargo and debris, special events, or any other event that significantly affects roadway operations
Accident	The collision of one motor vehicle with another road user, a stationary object, or person
Extraordinary congestion	Congestion caused by extraordinary events like traffic accidents, road works, or weather events
Vehicle breakdown	The operational failure of a motor vehicle such that the vehicle is stationary
Debris	Rubble, wreckage, litter and discarded garbage/refuse/trash, scattered remains of something destroyed
Recurrent congestion	Predictable congestion caused by sheer weight of traffic, for example during rush hours
Vehicle fire	Vehicles on fire on or next to the road. This is regarded as a special case of vehicle breakdown
Slow moving vehicles	Vehicles moving much slower than normal traffic
Pedestrians	Pedestrians walking on, or next to, a motorway
Limited visibility	Visibility restrictions caused by (for example) smoke, fog, bad weather
Wrong-way driving	A motor vehicle driving against the direction of traffic
Illegal lane use	A motor vehicle using a closed lane, or a vehicle crossing a solid line
Detection Rate	Ratio or percentage of the number of detected incidents to the total number of actual incidents during a given time period
Detection Time	Time delay between occurrence and detection of an incident.
False Alarm Rate	Ratio or percentage of false positive detections per unit of road length and unit of time, as a measure of operator work load (see [1], section 4.2, for FAR definitions); i.e. [number of false alarms / km / day]
Detection Accuracy	Detection Location Accuracy is the distance between the real and the detected incident location
Penetration rate of Equipped Vehicles	The ratio of vehicles that have the equipment installed and activated. In this report, the PEV is defined as the ratio of vehicles that have the equipment installed *and* activated. Vehicles that do not have the equipment or applications activated or have lost communication, are regarded as unequipped vehicles from the perspective of road side incident detection.

Abbreviations

Abbreviation	Meaning
AID	Automatic Incident Detection
ANPR / ALPR	Automatic Number/License Plate Recognition
CAM	Cooperative Awareness Message
DR	Detection Rate
DENM	Distributed Environmental Notification Message
DT / TTD	Detection Time, Time To Detect, or detection delay
E-Call	Pan-European in-vehicle emergency call system
EETS	European Electronic Toll Service
IR	Incident Rate
ETS	Electronic Toll Services
FAR	False Alarm Rate
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HGV	Heavy Goods Vehicles
ILD	Inductive Loop Detector
MIDAS	Motorway Incident Detection and Automated Signalling
MDIR	Manual Driver Intervention Rate
NRA	National Road Authority
ND	Nomadic Device
OBU	On-Board Unit
PC	Passenger Car
PEV	Penetration rate of Equipped Vehicles
PSAP	Public-Safety Answering Point
RIS	Road side ITS Station, i.e. a cooperative road side unit
UTC	Urban Traffic Control
V2I / I2V	Vehicle to infrastructure communication of cooperative ITS stations
V2V	Vehicle to vehicle communication of cooperative ITS stations
VIDS / VIPS	Video Incident Detection System / Video Image Processing System
VIN	Vehicle Identification Data or Vehicle Identification Sequence
VIS	Vehicle ITS Station; i.e. the OBU of a cooperative vehicle
WMI	World Manufacturer Index

Subscripts	**Detection source or system of performance measures**
A, B, C	Accident (A), Breakdown (B), Congestion (C)
eCall	eCall (section 5.1.1)
FCD	Floating Car Data (section 4.1.2)
RS	Road side detector
RSP	Road side point detections of passing vehicles (section 4.1.1)
RSTD	Road side point measurement of traffic data (section 4.1.1)
RST	Road side tracking (section 0)
TT	Travel Time (section 0)
ND	Nomadic Device (section 4.1.2)
NDT	Nomadic Device for tracking (section 4.3.3)
NDA, NDB, NBC	Nomadic Device for accidents (NDA), breakdowns (NDB) and traffic jams (NDC) (section 5)
SPTD	Service Provider traffic data (section 4.1.2)
V2I	Vehicle ITS Station to infrastructure (section 0)
IVT	In-vehicle tracking (section 0)
major	F_{major} is a factor of (major accidents / all accidents) (section 2.4)

1 Introduction

RAIDER (Realising Advanced Incident Detection on European Roads) is a research project funded within the framework of ERA NET ROAD by the National Road Administrations of Belgium, Switzerland, Germany, Netherlands, Norway and United Kingdom. The project assesses how to improve incident detection systems by incorporating new technologies for roadside systems and utilizing in-vehicle systems and nomadic devices. Improvements in incident detection are expressed in terms of detection quality and the estimated costs and benefits of the detection systems.

The main objective of RAIDER is to develop generic specifications for incorporating new technologies for incident detection, and requirements for the functionality and performance of the major components of the systems. The project, which began in November 2011 and runs to July 2013 is being carried out by a consortium comprising TNO from the Netherlands, AIT from Austria, TRL from the UK and FEHRL based in Belgium.

Incident detection is an essential capability for Road Authorities to manage their road networks and adequately respond to incidents. Incidents, such as accidents, broken down vehicles and congestion, directly impact traffic safety and efficiency. Automatic detection of incidents can significantly improve incident management, traffic safety and efficiency.

Existing systems for automatic incident detection are primarily road side based systems to detect congestion, such as inductive loops, video camera or radar systems. These systems require high setup and maintenance costs and only installed in vital sections of the network. A large part of the motorway network and almost all secondary roads in Europe are not equipped with incident detection systems. Existing systems frequently experience operational issues with the quality of detection, such as a high false alarm rate, delays in detection, or inaccurate location of incidents, that directly impact the effectiveness of the systems and result in increased costs of operations. Significant investments are required to improve the detection quality with additional roadside detection systems, and to extend the network with incident detection.

New developments in road side systems, nomadic devices, third party services and in-vehicle systems may provide solutions that improve both incident detection quality and reduce the costs for National Road Authorities. When and how can these technologies be applied or integrated into existing detection systems to improve the detection performance in a cost effective manner?

The answer depends very much on the existing situation and the desired situation of a National Road Authorities (NRA). Different technologies are relevant for different types of incidents, types of roads, traffic volumes, the existing detection systems to upgrade, retrofit or replace. The requirements and priorities for the desired situation can be diverse. The NRA may wish to reduce costs while maintain a certain level of detection performance, or improve the performance for specific types of incidents. Every Use Case could be considered separately for a tailor made solutions. RAIDER presents a different approach.

A methodology is presented in section 3 for a generic approach that is based on the following principles:

- An incident detection system can be segregated into data sources and incident applications of the NRA:
    - Road side systems, nomadic devices and cooperative systems are data sources that provide input to incident applications.
        - Data sources provide data of some data type, such as traffic data, travel time, or events
    - Applications using source data of some type as input to data fusion and incident detection algorithms.

    - The quality of data provided by a data source can be defined in quality parameters that are specific to the type of data, such as the detection rate, detection time and detection accuracy.
    - The detection performance of a detection application can be expressed in generic criteria; Detection rate, detection accuracy, detection time and false alarm rate

- The system configuration of an incident detection system defines the configuration of the data source(s) and the detection application.
    - The configuration of a data source is defined by the technology, and technology specific configuration parameters, such as the distance or density of road side sensors, or the penetration rate of vehicles and the vehicle equipment.
    - The detection performance of an application is determined by the algorithms for data fusion and incident detection, and the quality of the data sources.

- An incident detection system can be tuned to optimise specific detection performance criteria at the expense of others in order to meet the detection requirements of the NRA.
    - The system configuration defines the primary parameters of data sources and applications.

Section 4 specifies the data quality of new and existing technologies in a generic way as generic specifications. For each data type, a generic specification defines a model of the type specific data quality parameters in terms of the configuration parameters of the data source. This allows the selection and evaluation of data sources providing the same type of data by their type specific data quality parameters.

Section 5 specifies the detection performance of incident applications in a generic way as generic specifications. For each application, a generic specification defines a model of the detection performance criteria in terms of the data quality parameters. This allows the selection and evaluation of data sources (new technologies) for alternative incident detection algorithms.

Annex 1 provides a Technology Library with fact sheets per technology. A fact sheet describes the characteristics of a technology, the most relevant system configuration parameters, data quality parameters, and the assessment of a technology in terms of benefits (i.e. detection performance) and costs. Annex 1 is presented are a reference to specific technologies while reading the main document.

Section 6 applies the methodology, and uses the generic specifications, as an example for NRAs on 5 specific Use Cases for 3 types of incidents that are most common in Europe. The three incident types considered are: accidents, broken down vehicles, and extraordinary congestion. The five most relevant Use Cases are defined in section 6, Table 29.

The methodology can be applied by the NRA to the specific Use Case of the NRA. Sections 4 and 5 can be applied directly as exemplified in section 6. Annex 2 provides guidelines for NRAs to refine the business case.

2 User Needs and Requirements

In the first phase of the project, the Road Authorities' user needs and requirements for incident detection systems were defined as well as their experiences on operational issues and products (RAIDER Deliverable D2.1 [1]). This section summarizes the results of the first phase that are needed for deriving generic specifications.

2.1 Stakeholder priorities

A stakeholder consultation, consisting of a web questionnaire and interviews, was carried out with Road Authorities to address the issues described above. The RAIDER consortium analysed the stakeholders' feedback for prioritisation of incident types. Specifically stakeholders were asked to indicate their first, second and third priority of incident type, and rate impact of incidents on safety and traffic flow.

The most relevant classes of incidents on motorways and secondary roads were identified and provide the focus of the project Three incident types were identified:

1. Accidents
2. Extraordinary congestion
3. Vehicle breakdown (including vehicle fire)

Points of consideration for the most relevant operational situations on motorways and secondary roads include:

- The detection of an incident in a live running lane is of fundamental importance as this may have a significant impact on both safety and congestion
- The absence of a hard shoulder or refuge area significantly increases the impact on safety, congestion and incident response
- Heavy goods vehicles involved in incidents increases the impact on congestion and incident response
- Ensuring the hard shoulder is clear of obstructions prior to opening as a running lane
- Delay in travel time due to extraordinary congestion is required input for strategic traffic management and traffic information (e.g. to give route advice to road users)
- Detection of the tail of the congestion is required for tactical traffic management (e.g. variable speed limits)
- Incident detection systems are not commonly used for minor roads
- Existing road side incident detection systems are not generally suitable for secondary and rural roads due to costs involved
- Immediate (i.e. below 1 min) detection of incidents in tunnels is required and is state of the art
- Floating car data, such as that from nomadic devices, is not commonly used by road operators

2.2 Incident Management

Incident detection is the first step that initiates the incident management process. Incident detection triggers the first alarm for the operator Figure 1. This project focusses on the first step of incident detection and how to improve incident detection systems. However, this step cannot be considered in isolation. The incident management process defines the user needs and requirements for improving incident detection. It also provides the first information on which the operator has to make decision. To ensure that the alarm is not false, the operator needs to verify the incident, assess the severity and initiate further response for traffic control, and possibly call for rescue and recovery services.

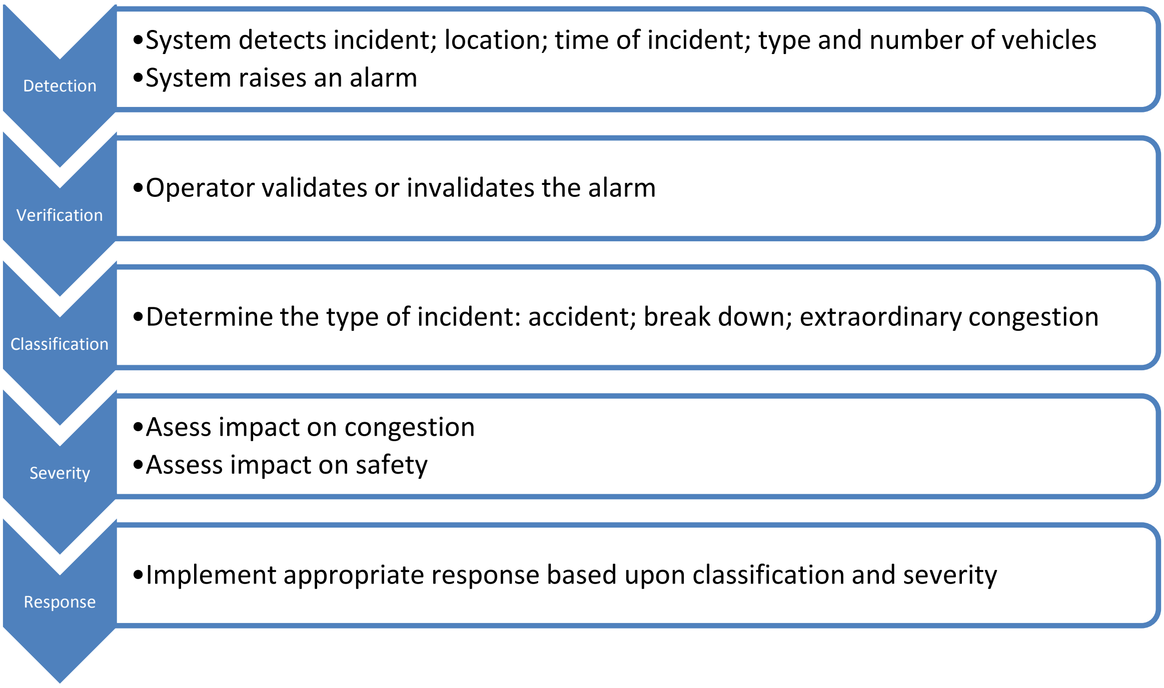

Figure 1: Incident Management process

EasyWay defines guidelines, recommendations and requirements for deployment and harmonization for Incident Warning and Management [2].

The most relevant functional requirements for incident detection are:

- Data and information collected must be based upon both a consistent geographic reference model and time validity model (i.e. DATEX II, CEN/TS 16157), and must contain the location and type of the incident.
- FR2: Detection/Discovery: Measures should be taken to detect incidents as early as possible in order to initiate early warnings and incident management. Detection can be done through both technology and human forces.
- FR3: Verification: the identification of the nature, accurate location and impact of an incident (e.g. the number of cars/Heavy Goods Vehicles involved, number of victims, damage, and dangerous goods) should be communicated between IM partners.
- FR11: Logging and monitoring reports should be produced, containing information about the nature, location and impact of the incident.

The most important objectives of the NRA's are:

- Traffic safety, especially to minimize the risk of secondary accidents.

- Organize rescue and recovery teams to clear the accident, and traffic measures to provide access for these teams to reach the accident.
- Minimize the number of false alarms to reduce the work load of traffic operators. In [3] a false alarm rate is suggested of 1 false alarm per day per direction per detector at 400m as an upper limit for Automatic Incident Detection "to gain credibility and make it a perennial solution".
- Reduce the costs of operating incident detection systems.

The most important requirements from the NRA's perspective dealt with in this report are:

- Early and automated detection of an incident to alert the traffic operator in the Traffic Control Centre.
- Accurate detection of the location of the incident, whether the running lane is blocked, number and type of vehicles involved. This may need additional means of verification such as CCTV cameras or cell phone call to services or from road users.

2.3 Detection performance

The criteria for measuring incident detection performance are defined in Table 1. The definitions are detailed in [1], section 4.2.

Table 1: Incident Detection Performance Criteria

Detection Rate	Ratio or percentage of the number of detected incidents to the total number of actual incidents during a given time period.	
Detection Time	Time delay between occurrence and detection of an incident.	
Detection Accuracy	Detection Accuracy is measured in different criteria, depending on the incident class:	
	Location accuracy	The distance between the real and the detected incident location.
	Number of vehicles	The capability to identify the number of vehicles involved in an accident.
	Vehicle class	The capability to distinguish between light vehicles such as passenger vehicles and light commercial vehicles, and heavy goods vehicles.
False Alarm Rate	Ratio or percentage of false positive detections per unit of road length and unit of time, as a measure of operator work load; i.e. [number of false alarms / km / day].	

Alternative definitions exist for the FAR. Here we use the definition relevant for the work load of a traffic operator as the ratio of false positive detections that are generated by the incident detection system as alarms and require intervention by the operator.

The accuracy of detections can be measured by multiple criteria relevant for the type of incident. Here we restrict the accuracy to criteria that can be detected automatically. Other relevant criteria, such as the number of injuries or casualties, cannot be detected with the technologies considered. Cooperative systems could provide information on the number of passengers in a vehicle, but not whether they are injured. Such information requires intervention from an operator, for example from CCTV cameras or via telecommunications to the passengers in vehicles (e.g. eCall).

The requirement for detection rate is influenced by the priority or severity of target incident under consideration; incidents considered to be of higher priority will require a higher detection rate such that missed incidents are minimised.

The requirement for detection accuracy is influenced by the information needed for decision making by the operator on type and severity of an incident and necessary response.

The requirement for detection time is influenced by the required response. Compromising the requirement on detection time will introduce delay and may ultimately impact the success of incident response; for example, emergency services access to the incident location will be restricted any incident related congestion that has built up since incident occurrence.

The requirement for false alarm rate is influenced by the operational environment (incident validation) in which it is deployed. Relaxation of the requirement on false alarm rates will introduce additional workload within the incident validation duties of system operators; there may be more false alarms to identify and cancel, and the efficiency of incident verification may be impacted as confidence in the system is reduced.

Although each different incident detection technology may experience characteristics inherent of the nature of the technology used; each system can be configured within any such constraints to optimise its performance against these factors. However, these performance factors are all interrelated; configuring a system to perform optimised to one of these requirements will negatively affect performance against the other parameters.

As Figure 2 shows, detection rate (DR) is directly proportional to the detection time (DT). Likewise, the false alarm rate (FAR) is inversely proportional to the detection time. When for example a more sophisticated detection algorithm would be used to improve the detection rate and reduce the false alarm rate, then the processing and detection time would increase. The opposite also holds; reducing the detection time, for example by using a simplified detection algorithm, or accepting alarms at lower thresholds, would negatively impact the false alarms and detection rate.

Detection Accuracy is a fourth dimension (not shown in Figure 2) to be optimised in relation to the others. The spacing of inductive loops for example directly affects the detection rate and detection time of congestion, as well as the accuracy of the location of the traffic jam.

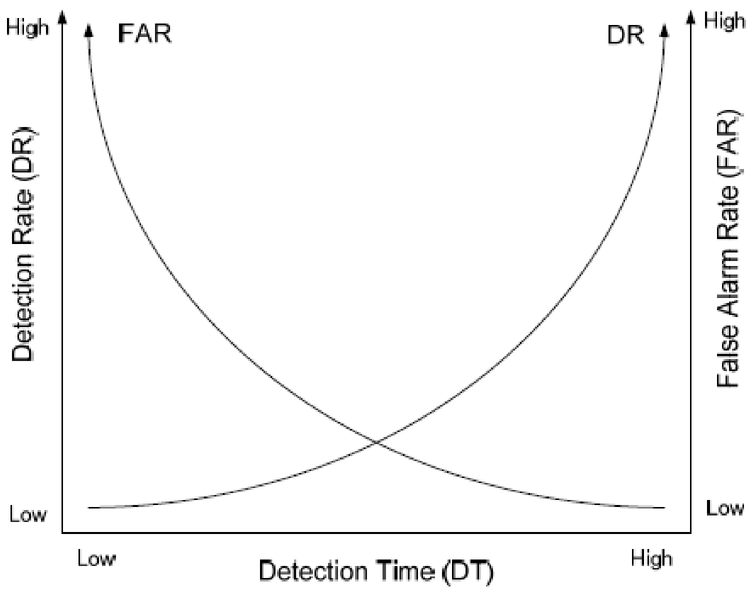

Figure 2: Incident detection performance relationships ([4] figure 7)

Table 2: Priorities for performance criteria

Incident Type	Severity	Response	System Configuration: Detection Rate	System Configuration: Detection Time	System Configuration: False Alarm Rate
Collision / Accidents	Damage Only	• Recover vehicle • Monitor congestion • Traffic management	✗	●	✓
	Minor	• Medical services as required • Recover vehicle • Monitor congestion • Traffic management	✓	●	✓
	Fatal / Major	• Immediate emergency response (fire, ambulance, police as required) • Medical services as required • Recover vehicle • Monitor congestion • Traffic management	✓	✓	✗ 1
Breakdown	Vehicle in safe refuge area	• Recover vehicle • Monitor congestion • Traffic management	✓	✗	✓
	Vehicle in live lane	• Retrieve vehicle to safe location • Recover vehicle • Monitor congestion • Traffic management	✓	✓	✗ 1
	Confined Space / no safe refuge	• Ensure driver and passengers are safe • Retrieve vehicle to safe location • Recover vehicle • Monitor congestion	✓	✓	✗ 1

Notes:

✓ – this factor is fundamental to timely/efficient response

✗ – this factor can be compromised (without negative impact)

● – this factor can be compromised (but will have negative impact on performance of the system)

1 – Compromising false alarm rate will require consideration of operational environment and user interface to ensure that incident validation is achieved in a simple manner

The importance of Figure 2 is that trade-offs have to be made between performance requirements and costs. Table 2 results from the user requirement analysis in [1] and shows the priorities of performance criteria in function of incident type, severity and incident response.

Defining performance requirements that are both appropriate and achievable require consideration of which factors are fundamental and which factors can be compromised to ensure timely/efficient response. Improving detection systems would require tailor made solutions for specific use cases or NRAs.

In the first stakeholder consultation three classes of incidents were selected as the most relevant [1]; accidents, vehicle breakdowns and extraordinary congestion. Important criteria for this selection are the severity of the incidents and commonality of the incidents in European countries.

2.4 Accidents

A traffic accident in road transport is defined in [1] as a collision between two or more vehicles, one vehicle and a roadside object or a vehicle and a pedestrian or animal. A traffic accident is caused by errant road user behaviour or a systematic problem.

The main user need for accident detection is to improve the safety of the vehicles and road users that are directly and indirectly involved in the accident. Timely and accurate detection allows the road operator to set traffic measures to minimize the risk on secondary accidents and disruption of traffic flow, and to provide access for rescue and recovery service vehicles, such as lane closures, speed limitations on variable message signs, and overtake restriction.

Therefore, even on low volume roads an immediate detection of such incidents is aimed for in Europe. In tunnels, immediate detection for accidents (i.e. below 1 min) is required and is followed by immediate actions to ensure safety. The existing technology with an immediate detection capability of accidents is typically a video based system (VIPS/VIDS) and these systems are standard equipment for tunnel safety.

Requirements on detection performance should be differentiated between higher risk road segments, such as tunnels, bridges and roads without a hard shoulder or refuge area, and between minor and major accidents. Whether an accident is minor or major can only be determined after detection and validation of the incident obviously. In high volume traffic, congestion will already build-up within the first minute after the accident. In higher risk areas, all running lanes will already be blocked within the first minute. Therefore the detection time should be an order of magnitude smaller (e.g. 10 seconds) for setting traffic measures effectively.

The highest priorities for the detection performance of automatic accident detection systems are:

1. Very high or high detection rate to minimize the risk of missing any major accidents in particular.
2. Low to medium detection time for generating a first alarm. The delay should be less than 1 minute for detection and lane closures in order to avoid the build-up of congestion on high volume roads.

An important requirement is the need to assess the severity of the accidents to distinguish between minor and major accidents, assess any personal injuries or casualties, and the location and class of the vehicles involved. In tunnels, this should also include the detection or assessment of vehicle fires. Commonly, video cameras are also required for the first visual assessment and validation of an alarm and for assessment of any personal injuries or casualties[1].

[1] RAIDER considers the detection of vehicles. The detection of injuries and casualties may require

For most accidents (except perhaps for damage only), the operator should support emergency or recovery services, reduce the time for emergency vehicles to reach the accident location, and enable easy access for services to the location. Lower priorities for the detection performance are:

3. The automatic detection system, or additional validation systems, should provide the information needed for classification and severity assessment.
4. Higher false alarm rates are acceptable for major accidents. For minor accidents, the false alarm rate should be low.

On high volume roads such as trunk roads and motorways automatic detection systems are installed to trigger other traffic management actions. For the secondary and rural road network accident detection systems are not commonly used due to the associated costs of equipment and resources needed for monitoring (per km), however, these roads exhibit the highest accident risks (e.g. [5]). Therefore, specific accident detection mechanisms for low volume, secondary and rural roads are required with very low costs (per network km monitored).

Several types of detection mechanisms will be distinguished in section 5.1:

- Automatic detection of sudden stationary objects on the road.
- Automatic detection of colliding vehicle trajectories.
- Automatic detection of a collision by in-vehicle sensors.
- Report by vehicle occupants or other road users.

2.5 Vehicle Breakdowns

A vehicle break-down incident is defined in [1] as the operational failure of a single motor vehicle such that the vehicle is slowed down considerably or becomes stationary. Usually, the stranded vehicle occupies a single lane or only part of a lane.

The exact cause of the vehicle failure is not essential for the road operator. Many causes of vehicle failures can be considered, such as mechanical failure, fire, out of fuel. Other causes like health issues of a driver or passenger will also result in vehicle stops.

The main user need for vehicle breakdown detection is to improve the safety of the vehicles and road users that are directly and indirectly involved in the incident. The location of the breakdown is the major differentiator for the impact on traffic flow and safety, the required operator actions and detection requirements.

If a vehicle breaks down in a location that directly affects traffic on a running lane, for example when a Heavy Goods Vehicle (HGV) breaks down and obstructs traffic on a running lane, the situation is comparable to that of a minor accident. The highest priorities for the detection performance of automatic detection systems are similar to accident detection:

1. Very high detection rate to minimize the risk of missing any broken down vehicle on or near a running lane.
2. Very low detection delay for generating a first alarm. The delay should be less than 1 minute for detection and lane closures in order to avoid the build-up of congestion on high volume roads.

The operator should support recovery services, reduce the time for recovery vehicles to reach the accident location, and enable easy access for services to the location. An important requirement is the need to validate and asses the exact location and lane of the stranded vehicle, whether it is a Heavy Goods Vehicle and dangerous goods are involved.

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different technologies than addressed here.

Lower priorities for the detection performance are:

3. The automatic detection system, or additional validation systems, should provide the information needed for classification and severity assessment.
4. Higher false alarm rates are acceptable.

If a vehicle breaks down on a location not directly effecting traffic on a running lane, such as on a refuge area, the priorities for detection are significantly different. The highest priority would be a low false alarm rate to minimize the work load of an operator. This situation is not considered in this project.

Several types of detection algorithms will be described in section 5.1.5:

- Automatic detection of malfunctioning by in-vehicle systems.
- Automatic detection of a vehicle trajectory pattern (slowing down to stationary).
- Automatic detection of a single stationary object on the road.
- Report by vehicle occupants or other road users.

2.6 Extraordinary Congestion

Extraordinary congestion is defined in [1] as the unpredicted congestion caused by extraordinary events like abnormal traffic flows, traffic accidents, broken down vehicles, vehicle fires, wrong-way-driving, road works, or weather events. An event is called extraordinary to distinguish the incidents from recurrent congestion at bottlenecks in the road network and capacity limitations during rush hours. The assumption here is that the cost benefit relation for incident detection systems at locations with recurrent congestion are significantly higher than for extraordinary congestion in the rest of the road network.

The previous subsections discussed the direct detection of incidents such as accidents and vehicle breakdowns. Such incidents may cause extraordinary congestion eventually as a secondary effect in high volume traffic. Such incidents can also be detected indirectly from the emerging congestion upstream of the incident. The detection of a traffic jam tail as a safety system to warn approaching drivers is commonly called “Automatic Incident Detection” (AID). The “incident” is defined as the build-up of extraordinary congestion. The underlying cause may be assessed from validation by an operator as an accident or breakdown, or may remain unknown.

Detection Time (DT) of the extraordinary congestion is defined as the time between start of congestion and the detection of the congestion, or the delay in the detection of the actual location of a jam tail. When congestion actual starts is rather difficult to define, e.g. when an accident occurs or when the average vehicle speeds drop below 40 km/h, so there is margin for various interpretations in literature.

The time between the occurrence of the cause and the start of congestion is variable and strongly depends on traffic flow and number of lanes for example. This time span can be in the order of 1 or more minutes and is not included in the detection time (DT) for extraordinary congestion. Obviously the DT of accidents and breakdowns cannot be compared to the DT of extraordinary congestion. This time difference is important in use cases where for example the hard shoulder has to be cleared for emergency services.

Detection of extraordinary congestion can be differentiated into the following sub-classes of incidents:

1. AID.
2. Detection of moving jams.
3. Detection of congested traffic and stationary jams.

Differentiation is needed because not every detection technology can be applied to detect incidents or moving jams for example. This is determined by the spatial and temporal resolution of the detection system. A rule of thumb for controlling a process (i.e. traffic) is to monitor the traffic with a resolution of one order of magnitude higher than the phenomenon (i.e. congestion) to be detected. This can be exemplified with a simple calculation and a comparison with a typical existing system using inductive loops at 500m distance with a sampling rate of 1 sample per minute:

1. Automatic Incident Detection:

   Congestion starts to build-up within 1 minute after an accident in high volume traffic. Once started, congestion grows with 5 m/s or 300 m/min. To detect the emerging congestion accurately, the sampling rate of the detection system should be in the order of 0.1 Hz and the spatial resolution should be 30 - 50 m.

   With the existing system, the first sample indicating the congestion can only be made after 1 – 2 min after the start of the congestion and the after the tail has crossed a loop. To actually confirm that it is a congestion, and that it is growing, will require several more samples till the congestion reaches a second or third pair of loops, thereby increasing the detection time to 5 or more minutes.

2. Detection of moving jam:

   A moving jam has a length in the order of 1 to 2 km and grows also with 5 m/s. To detect and follow the progress of a moving jam accurately, a spatial resolution of 100-200 m is needed and a sampling rate of 0.3 Hz.

   With the existing system, the jam covers three or four loops at a time, and moves to a next loop point in one or two samples later. To accurately estimate the length and speed of the jam would require filtering over a 5 to 10 samples.

3. Detection of congested traffic and stationary jams:

   The objective for detecting only the presence of congestion is for traffic efficiency and routing, and detection delay of 5 or more minutes, and a location accuracy of +/- 500 m is usually acceptable.

In existing detection systems congestion is commonly detected with inductive loops. Loops that are installed with an intermediate distance of several hundred meters are enough to detect and to quantify congestion. The tail of the congestion can also be determined with these loops. Only areas with busy traffic are equipped with these sensors; areas with less heavy traffic are usually not equipped.

Road segments with recurrent congestion may of course already be equipped with adequate detection systems that can also detect extraordinary congestion. Here we focus on road segments without existing congestion detection such as secondary roads where relatively inexpensive and permanent congestion detection is needed.

For traffic safety, the tail of the congestion must be detected in order to warn traffic behind and reduce the risk of secondary incidents. The wave speed of the traffic jam tail determines the allowable time delay for warning drivers. A traffic jam usually grows at about 5 to 6 m/s. The tail front travels a distance of 500m between two loops in about 1.5 minutes. Based on this situation, the tail of the congestion has to be determined with a precision of at least a few hundred meters. To warn drivers in time on the gantry 500m further upstream, the detection time should be less than one minute.

In combination with Automatic Incident Detection (AID) systems, traffic measures should not be set unnecessarily. Operators should not be annoyed by false alarms typically generated for slow moving vehicles.

The priorities for extraordinary congestion detection are set to:

1. The required detection rate is estimated to be lower than for accidents
2. The false alarm rate should be low and should not exceed 1 false alarm per loop segment per day (section 2.2, [3]).
3. Detection accuracy and time can be an order of magnitude smaller than for accidents and breakdowns. The performance of existing systems from above are regarded as minimum requirements:
    - Location accuracy < 500m, preferably < 100m
    - Detection time for congestion detection < 1 minute
    - Recommendations for travel time monitoring are:
        i. Update frequency < 1 minute for high volume motorways
        ii. Update frequency < 5 minutes for low volume motorways
        iii. Update frequency < 15 minutes for secondary roads with no recurrent congestion

Detection accuracy of congestion also includes the type of congestion that can be detected, in addition to the accuracy of the location of the congestion. Following types of congestion can be distinguished as not all detection technologies may be able to detect these:

- Automatic Incident Detection which is essentially the detection of congestion building up immediately after an incident when traffic volume is sufficiently high.
- Moving jams that typically span a jam length in the order of 1 or 2 km and move with a wave speed of 5 to 6 km/h.
- Stationary traffic jams, typically at bottlenecks, that can extend in length from 100m to many kilometres. Here, stop and go traffic jams are included.

Although inductive loops are currently the most common form of congestion detection, other types of sensors like radar or video are also used. The outputs of these sensors for this application are similar to inductive loops; flow and speed and mostly aggregated to one minute values.

Congestion can also be measured by nomadic devices. More and more route navigation applications can transmit their speed or travel time to a central server that provides other road users with that information.

Furthermore travel time is measured by ANPR cameras or Bluetooth detectors at the start and end of a route. This information is more sparse, because the density of these sensors is mostly less than inductive loops.

Several types of detection mechanisms will be used in section 4:

- Traffic data from point measurements (measure averages over all vehicles: flow, speed, density)
- Travel time delay (identify specific vehicles at multiple locations)
- Detection of traffic jams and stop & go traffic by in-vehicle sensors
- Events detected by vehicle occupants or other road users

Several types of congestion detection algorithms will be used in section 5.3:

- Traffic state estimation (measure averages over all vehicles: flow, speed, density)
- Travel time delay (identify specific vehicles at multiple locations)
- Vehicle tracking

2.7 Incident statistics

Using the strategic network of the United Kingdom as an example; the following statistics demonstrate the frequency and impact of the various incident types considered within this study (see Table 3).

Some key findings:

- Breakdown, debris and collisions account for 90% of all incidents reported on the Highways Agency network
- There is a clear relationship between collision severity and associated impact
- Fatal accidents are about 3.4% of the accidents with injuries (serious or minor).
- Fatal accidents are about 0.9% of the total accidents with collisions, and about 0.17% of the total incidents
- Accidents with injuries (serious and minor) are about 27% of the total number of accidents, and about 5.0% of the total incidents.
- Although a significant proportion of incidents reported are the presence of 'debris'; the impact of these incidents is minor when compared to the impact arising from either breakdowns or collisions.
- Although vehicle fire incidents are infrequent; the impact is substantial.

Vehicle fire incidents are to be considered specifically as a subset of breakdowns.

Table 3: Motorway incident statistics from the UK

Incident Type	*Number of incidents (% of total number of incidents)*	*Average time of impact on live carriageway*
Total	**141,674**	**~ 30 minutes**
Breakdown	58,224 (41%)	~ 27 minutes
Debris	41,217 (29%)	~ 14 minutes
Collision, of which:	26,285 (19%)	
- *Damage*	*18,944*	*~ 40 minutes*
- *Minor Injury*	*4,768*	*~ 72 minutes*
- *Serious*	*2,335*	*~ 114 minutes*
- *Fatal*	*238*	*~ 393 minutes*
Vehicle Fire	1,529 (1%)	~90 minutes
Wrong way driving	130 (0.09%)	~15 minutes

Notes:

1. *Statistics are extrapolated from incident database as provided by the Highways Agency, UK*
2. *Statistics cover all incidents reported on the HA network between August 2010 and December 2011*
3. *Ordinary & extraordinary congestion are not recorded as an "incident" so do not feature within this data*

In [5] the accident statistics for 27 European countries (EU27) are divided into fatalities and accidents with injuries. Table 4 summarizes some results for the European average and for four countries to exemplify the variability between countries. The four countries are selected arbitrarily as examples of relatively low and high accident rates. The results from [5] are used to derive the average number of reported accidents per year and km of road type as input to estimates in the following sections. Some observations can be made:

- The number of fatal accidents varies significantly between countries, e.g. by a factor of 4.
- The number of fatal accidents averaged per km of motorways can be an order of 10 higher than on the secondary roads (NL, UK).
- The number of fatal accidents per km on secondary roads varies significantly between countries, e.g. by a factor of 10.
- The accidents on motorways are primarily accidents with vehicles, while the accidents on secondary and other roads also include other road users such as pedestrians and bicyclists.
- The ratio between fatal accidents and accidents with injuries varies significantly between countries by a factor of 20.

The total number of fatal accidents on the motorway in the UK (203) is comparable to the statistics from 2010 and 2011 in Table 3 (238). The total number of accidents with injuries on all roads (189100 in Table 4) far exceeds the accidents on motorways (2335 + 4768 in Table 3) as expected. The ratio between fatalities and injuries on all roads (1.7% Table 4) is about half the ratio on the motorways (3.4% in Table 3) due to inclusion of other road users and traffic conditions.

Table 4: Accident statistics from all road types in Europe in 2006 from [5]

	EU 27	*NL*	*UK*	*PL*	*RO*
fatalities/Year motorway		151	203	32	
fatalities/Year secondary - not urban		531	1931	2917	
fatalities/Years urban		346	1302	2495	
fatalities/Year in 2006 total	42953	730	3297	5243	2478
Motorways [km]	67100	2500	3600	600	200
National roads [km]	345500	6700	48900	18300	15700
Secondary and regional roads [km]	1422800	57500	122200	28400	64000
other roads [km]	4125700	59400	238100	377300	27800
Total [km]	5961100	126100	412900	424500	107700
fatalities/Year/km motorway		0.0604	0.0564	0.0533	
fatalities/Year/km secondary		0.0083	0.0113	0.0625	
fatalities/Year/km urban		0.0058	0.0055	0.0066	
fatalities/Year/km total	0.0072	0.0058	0.0080	0.0124	0.0230
accidents with injuries/Year total	142200	24500	189100	46800	7800
fatalities / accidents with injuries	30.2%	3.0%	1.7%	11.2%	31.8%

In the absence of more accurate data, the number of incidents has to be estimated from Table 3 and Table 4. Due to differences in traffic conditions and road users the ratio between fatalities and injuries will be different between motorways, secondary roads and other roads. We assume that the ratio of fatalities and injuries in accidents on secondary roads to be 1.7% instead of 3.4%, resulting in a ratio of fatal incidents of 0.09% of the total incidents on secondary roads. The distribution of road incidents remains similar to Table 3.

Table 5 combines the results from Table 3 and Table 4. The incident rates for accidents per year and per km (IR_A) will be used as estimates for performance assessments in this report. About 5.17% of all incidents are accidents with injuries or fatalities, which is about 25% of all accidents. This percentage is taken as an estimate for the fraction of major accidents or emergency situations intended to be detected or reported via the eCall system:

$$F_{major} = 25\%$$

Table 5: Accident rates per km of road – scaled from Table 3 and Table 4.

	Motorway		*Secondary roads*	
	incident distribution from Table 1	incidents /Year /km	incident distribution from Table 1	incidents /Year /km
fatalities	0.17%	0.0564	0.09%	0.0113
accidents with injuries	5.00%	1.6585	5.00%	0.6639
total accidents	19.00%	6.3023	19.00%	2.5227
breakdown + vehicle fire	42.00%	13.9314	42.00%	5.5765

3 Methodology for assessing innovative detection technologies

The methodology sketched in Figure 3 is used to generate and assess relevant options for innovating detection systems. The individual steps will be explained in this section, and applied in the next sections.

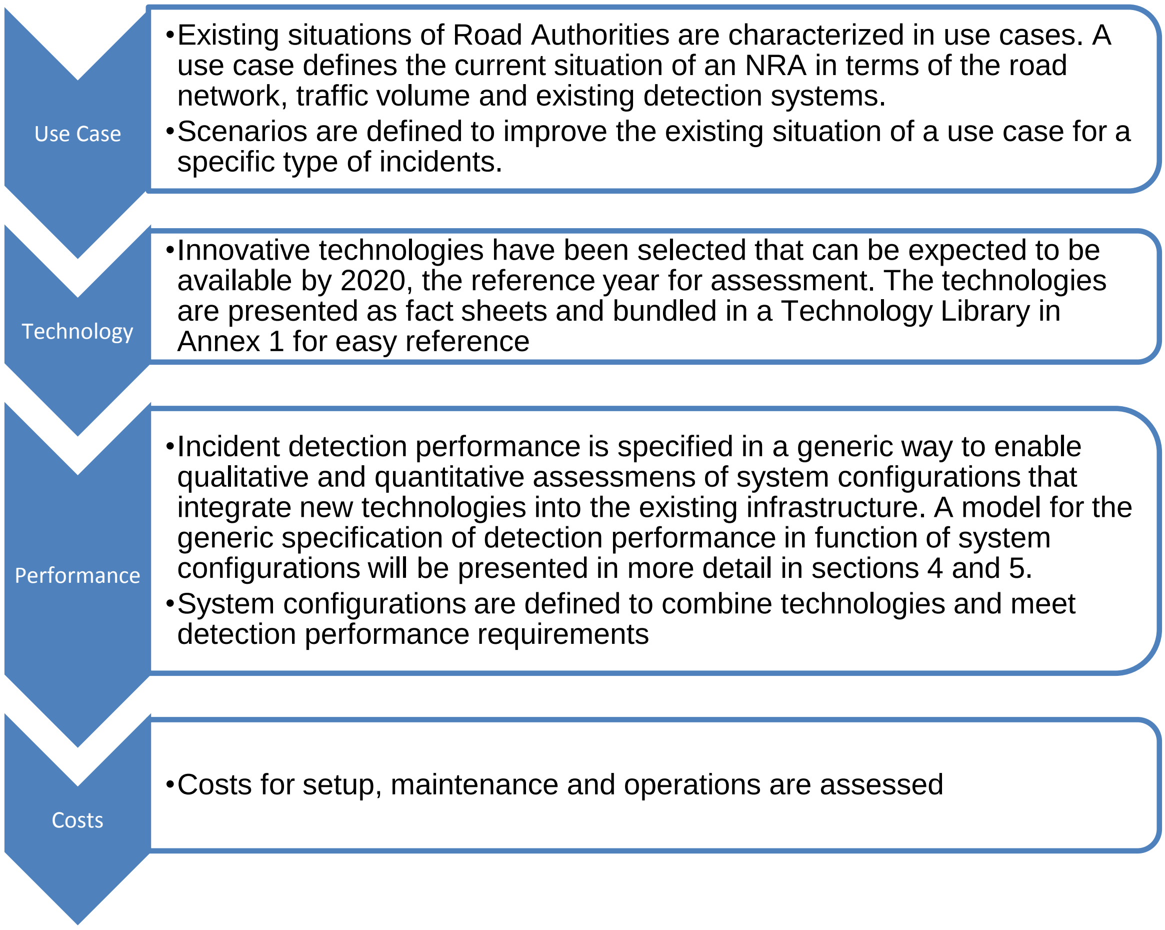


Figure 3: Methodology for assessing innovative detection technologies

Section 6 presents the most relevant Use Cases and their assessments as examples of the methodology.

3.1 Use Cases

A Use Case describes a typical scenario of an existing situation of an NRA with the existing detection systems and traffic situation. This allows RAIDER to select the most relevant future technologies that improve detection performance and/or provide cost benefits with respect to the existing situation. Generic specifications can then be developed for implementing a future technology or a combination thereof.

The following figure sketches the three aspects characterizing an existing situation with a network type, traffic flow and the existing incident detection system(s).

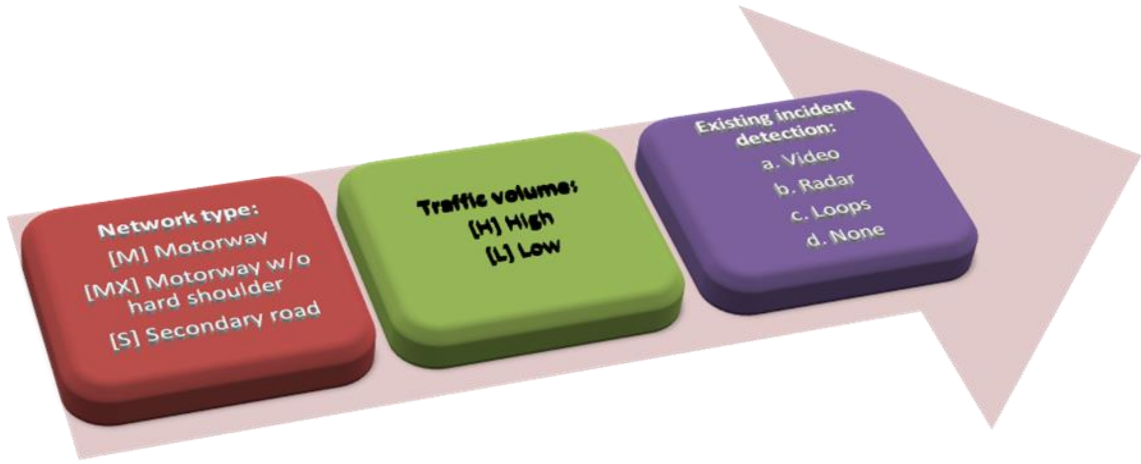


Figure 4: Use Cases

3.1.1 Network Type

The network describes the physical characteristics of the road [6]. Here we distinguish motorways and secondary roads.

A motorway has two or more lanes in both driving directions with separation of the carriageways of each direction, no intersections with other roads (intersections are handled by over- and under-passes with interchanges), toll or no-toll motorway.

Secondary roads are two- or four-lane roads with lane in each direction, no physical separation between driving directions, and ground level intersections with other roads.

Following network types are identified:

[M] – Motorway with hard shoulder: Any route with grade separated interchanges with a continuous non-running lane for refuge

[MX] – Motorway without hard shoulder: Any other route with grade separated interchanges without a continuous non-running lane for refuge. May be a tunnel, bridge, elevated section, section of network with active hard shoulder running.

[S] – Secondary or Arterial Road: Any route with at-grade intersections, may be urban or rural, a dual or single carriage way (with or without a central median separating traffic of opposing directions).

EasyWay [6] defines Operating Environments e.g. in terms of the physical characteristics of the road, and traffic flow and safety concerns, that will be used here as well.

3.1.2 Traffic Volume and Flow

The volume of traffic can be directly linked to traffic safety conditions and on the performance of incident detection systems. In high volume traffic recurring or extraordinary congestion problems occur and incidents occur more frequently than in low volume traffic. The risk on secondary incidents is also different. In high volume traffic, an accident or break down will result in congestion shortly afterwards and the risk of secondary incidents like head-tail collisions arises for vehicles approaching the tail of the traffic jam and in stop and go traffic. In low volume traffic, the remaining road capacity is sufficient to avoid congestion and the risk of secondary accidents like collisions are smaller. However, the effects of any collisions are more severe due to the higher speeds of approaching vehicles.

The traffic condition is characterized by the traffic flow. On roads with a high traffic flow, an incident like an accident or vehicle breakdown may immediately cause congestion. On roads with a low traffic flow, such incidents may not lead to congestion, but due to the large speed differences the incident has an increased safety risk.

[H] – High Flow: any route subject to either high average flow or high peak flow

[H] = { Average Flow > X AADT/lane } OR { Peak Flow > Y VPH/lane }

[L] – Low Flow: any route that does not have either high average flow or high peak flow

[L] = { Average Flow < X AADT/lane } AND { Peak Flow < Y VPH/lane }

Where:

Average Flow: is the expected traffic flow for a route that is normalised for seasonal, day and time of day variations. A common measure for Average Flow is:

AADT (annual averaged daily traffic) - the total volume of vehicle traffic of a highway or road for a year divided by 365 days

Peak Flow: is the maximum traffic flow that can ordinarily be expected for a route. A common measure for Peak Flow is:

VPH/lane (vehicles per hour per lane) – the total number of vehicles passing a point within a fixed period of time divided by the period of time (as a ratio of hours) and the number of lanes available at the point in question.

A threshold value to distinguish high and low flow is location dependent. Typical values could be chosen as:

- Average flows exceeding 25000 Annual Average Daily Traffic per lane (AADT/lane) can be considered highly trafficked.
- Peak flows exceeding 1600 vehicles per hour per lane (VPH/lane) can be expected to cause congestion.

3.1.3 Existing detection systems

Currently the level of monitoring infrastructure coverage on the TERN, in relation to road length (density of monitoring), varies between 5% and 100% in different countries and depending on the monitoring function concerned [3].

A NRA may have one of the following existing systems in place for traffic or incident detection.

1. No existing system (i.e. a totally new system is required)
2. Inductive loop detectors, at a typical spacing of 500m
3. Video system
4. Inductive loops and video systems
5. Radar systems
6. Tolling system including radar and video systems

Please note that the existing video and radar systems considered are the existing commercial systems for traffic detection (point measurements), such as VIDS. These do not include the innovative technologies for tracking vehicles (see [1] for more details).

Also note that the existing detection systems may not be adequate for detecting all types of incidents considered here, such as accidents and vehicle breakdowns.

3.2 Innovations in incident detection technology

Typically, Road Authorities and Road Operators will have to invest and take action to improve their road side incident detection systems. For nomadic devices and cooperative systems on the other hand, several trends in technological developments and legislation can be identified upfront that are likely to occur in the near future. These developments may significantly change the technology situation in 2020, even if NRA's "do nothing" to improve their current incident detection systems. This section presents scenarios of the technology situation assumed to be accomplished and representative of an "existing technology situation" by 2020 for the development of generic specifications. The technologies are discussed in more detail in Annex 1, together with the assessment of their detection performance and costs.

3.2.1 Nomadic Devices

Nomadic devices such as smartphone, tablets, and navigation devices have already reached a high market penetration today. These devices usually have a GNSS receiver, accelerometers, camera, microphone, gyroscope, magnetometer, Bluetooth, navigation and traffic information services and mobile internet. The UMTS Forum [7] expects a large increase in data rates and penetration by 2020 due to e.g. the capacity of telecommunications networks, and technology from 3G/UMTS to 4G/LTE. It is currently estimated that smartphone use is already above 50% in Western Europe. By 2020 the market penetration is expected to be very high and ubiquitous and no significant limitations in data rates for the exchange of traffic and incident related data are to be expected across Europe.

More importantly are the type and costs of services and applications being developed that can support the detection and verification of traffic information and traffic incidents. Services or applications on nomadic devices are already capable of detecting congestion on the complete road network. Nomadic devices are not yet connected to in-vehicle sensors and systems that detect an accident or vehicle breakdown. Applications and services are also available to manually announce the accident or breakdown. It should be noted that the effective penetration rate of nomadic devices in vehicles also depends on the conditions and registrations for specific services.

Important considerations for future scenarios are:

- The effect of penetration rate, communication and provided services on the accuracy and time delay of the information provided to a traffic operator.
- Standardisation of the integration with in-vehicle systems.

3.2.2 eCall

eCall is an in-vehicle emergency system that automatically calls the alarm centre or PSAP and sends the most relevant accident information to initiate emergency response. The call is made automatically when a vehicle crash is detected by in-vehicle systems. Alternatively passengers can activate the system manually, for example in case of a heart attack or to report an accident witnessed. The call also provides the voice communication to enable the PSAP to acquire more information from the passengers. The main objective of eCall is to reduce the time to respond for emergency services.

In [8] the penetration rate of eCall equipped vehicles was estimated for the regulatory deployment scenario to 30 - 40% by 2020, when eCall is made mandatory on all new vehicles from 2015 onwards. However, eCall will only be mandatory in all new vehicle model designs after 2015, and a penetration rate of only 10% seems more likely. On the other hand, when eCall will be integrated with other services and cooperative applications, for example as in [9], and provided in aftermarket products, then higher rates are likely. The penetration rate of vehicles equipped with eCall in 2020 assumed in this report is:

$$PEV_{eCall} = 10\% \text{ by } 2020$$

$$PEV_{eCall} = 90\% \text{ by } 2030$$

The event generated by an eCall system can also serve as an accident or incident detection to alarm the traffic operator, and potentially as a means to verify the accident and collect additional information. However, incident detection is not yet part of the standardisation of the mandatory eCall system. To make use of eCall for incident detection and verification, it is important to investigate the conditions and requirements. This seems technically feasible and eCall is considered a feasible and relevant innovative detection system in this report. A more detailed description of eCall for accident detection is provided in Annex 1.1.

3.2.3 Cooperative ITS

A cooperative ITS is an Intelligent Transportation System in which vehicles, road infrastructure and back offices cooperate to improve active road safety and traffic efficiency. The cooperative vehicles and road side units have an ITS Station with a standardised architecture including a communication unit and an application unit. ITS Stations communicate with other ITS Stations via short range communication (ITS G5 - 802.11p) or via a mobile cellular network communication (3G – 4G).

A Basic Set of Applications for the first generation of ITS Stations include safety and traffic related applications to inform or warn drivers, e.g. for accidents, broken down vehicles or congestion. ITS Stations in vehicles or road side units detect these incidents from on-board sensors and systems. The detections and messages from these vehicles provide high quality data for incident detection of road operators.

Cooperative ITS is an emerging technology. Demonstration or prototype systems are being field tested. European vehicle manufacturers intend to bring the first cooperative systems to the market in 2015 [10]. Road authorities are starting up initiatives to develop a road side infrastructure at specific locations and TERN corridors. The penetration rate of equipped vehicles is estimated in 0:

$$PEV_{V2I} = 5\ \% \text{ by } 2020$$

3.2.4 Positioning

Nomadic devices and in-vehicle devices have global positioning systems, using a Global Navigation Satellite System (GNSS). Current systems are most commonly using GPS that have a typical positioning accuracy of 10 m or worse and do not provide lane-level accuracy. Consequently these devices cannot be used to determine which lane is blocked by a traffic queue, or whether an accident or broken down vehicle is on a running lane or refuge area.

New developments like EGNOS and Galileo, and combination with inertial navigation systems, should improve positioning to an accuracy of less than 1 m [11], which is sufficient for lane level accuracy. [12] estimates that by 2020 90% of the market of navigation devices will use Galileo.

Current in-vehicle positioning systems use GPS receivers. Their positioning accuracy can already be improved to less than 10 m with inertial navigation systems using on-board sensors and vehicle state estimation systems.

3.2.5 Road side detectors

Existing road side detectors, such as inductive loop detectors, video and radar detectors, are still being developed further to improve detection performance and reduce costs. One trend is the combination of sensor technologies to increase the robustness for various environmental and adverse weather conditions. Examples are the integration of radar, laser, video, and thermal imaging. However, these developments do not provide essentially different types of detection data, new options for improving to incident detection, or major cost savings. The performance models of sections 4 and 5 still apply and enable the NRA to incorporate such new developments as alternatives of existing technologies.

A development trend that does provide a new type to data for accident and breakdown detections are road side tracking systems. Examples are video tracking, radar and laser scanners. These technologies provide vehicle tracking data comparable to the tracking systems of in-vehicle systems and nomadic devices. There are some fundamental differences of course between road side and vehicle based tracking systems, such as the spatial coverage and the percentage of tracked vehicles. As such road side tracking systems provide an interesting option for incident detection in the next few years.

3.3 Performance considerations

Detection performance needs to be considered for existing systems, innovative technologies, and for the integrated system combining the two. However, detection performance not only depends on the technologies used, is also strongly depends on the Use Case and system configuration (section 2.3). The enable a generic and qualitative assessment of technologies, the following two step methodology is applied:

1. The requirements for incident detection (section 2) and the performance of technologies (Annex 1) are expressed on the same qualitative scales to enable comparisons and combinations of technology options.
2. Generic models are defined to assess the performance of technologies and detection systems in function of main system configuration parameters.

3.3.1 Quantitative performance

The following requirements on the performance criteria are taken either from section 2, from references (e.g. [13]) or as educated guesses.

Detection Rate

The requirement for detection rate is influenced by the priority or severity of target incident under consideration; incidents considered to be of higher priority will require a higher detection rate such that missed incidents are minimised. The detection rates are qualified as:

	Low	Medium	High	Very High
Detection Rate (DR)	<= 50%	> 50%	> 80%	> 99%

Detection Time

The requirement for detection time is influenced by the required response and ultimately restricted by the existing mechanism for detection/notification (for example, phone call received from road user or police). Compromising the requirement on detection time will introduce delay and may ultimately impact the success of incident response; for example, emergency services access to the incident location will be restricted by any incident related congestion that has built up since incident occurrence. The detection time is qualified as:

	Low	Medium	High	Very High
Detection Time (DT)	< 10 sec	< 1 min	< 5 min	>= 5 min

Detection Accuracy

Detection accuracy is for most incidents interpreted as the accuracy of the location of the incident or the location of the tracked vehicle. There is an inherent trade-off between location precision and system cost. An incident detection system can be designed to optimise precision location without significant impact on performance, but this is generally achieved by increasing coverage of the system (for example, closer spaced detectors).

For accidents and breakdowns the detection accuracy is qualified as very high, if the lane can be determined of the vehicle(s) involved in the incident. This is relevant to distinguish between incidents on running lanes or hard shoulders for example. For congestion the location refers to the start and end of traffic jams. Detection accuracy is qualified as:

	Very High	High	Medium	Low
Location Accuracy (LA)	Lane accurate < 1 m	< 10 m	< 100 m	>= 100 m

For accidents and breakdowns, detection accuracy also includes the identification of the vehicle class and the presence of dangerous goods.

False Alarm Rate

The requirement for false alarm rate is influenced by the operational environment (incident validation) in which it is deployed. Relaxation of the requirement on false alarm rates will introduce additional workload within the incident validation duties of system operators; there may be more false alarms to identify and cancel, and the efficiency of incident verification may be impacted as confidence in the system is reduced. The qualification of acceptable FARs strongly depends on the safety risk when a detection is missed.

For accidents and breakdowns, an acceptable FAR is set to 2.5 FA/day/km [3] (section 2.2), which is interpreted the upper limit of Medium. The threshold for a low FAR is set an order of magnitude smaller to represent the requirement of a minimal extra workload for the operator for less critical and larger parts of the road network.

	Low	Medium	High	Very High
False Alarm Rate (FAR) [False Alarms/day/km]	< 0.25 FA/day/km	< 2.5 FA/day/km	< 25 FA/day/km	>= 25 FA/Day/km

Suitability

The suitability of technologies is evaluated as the measure in which the technology can satisfy the four performance requirements from above (i.e. DR, DT, DA, FAR).

	Low	Medium	High	Very High
Suitability	Does not satisfy all high priority requirements	Satisfies all high priority minimum requirements	Satisfies all *minimum* performance requirements	Satisfies all performance requirements

3.3.2 Detection performance models

The performance of a detection system is the net result of the performance of its main components; sensors, data fusion component(s) and the incident detection algorithm that generates the alarms. Detection performance depends not only on the detection technologies used, but also on the performance of the system components, the system configuration, Use Case (e.g. traffic characteristics) and environmental conditions (e.g. adverse weather). Technologies from Annex 1 are either sensors or detection systems on their own. This makes the comparisons and integration of technologies even more difficult.

Alternatively, a technology from Annex 1 can be regarded as a data source that provide input to the incident algorithm that generates alarms for the operators (Figure 5). A data source provides data of some type as input to a detection algorithm. If multiple technologies are used as sources, then the input is provided to a data fusion component, that itself provides input of a similar type to the incident detection algorithm.

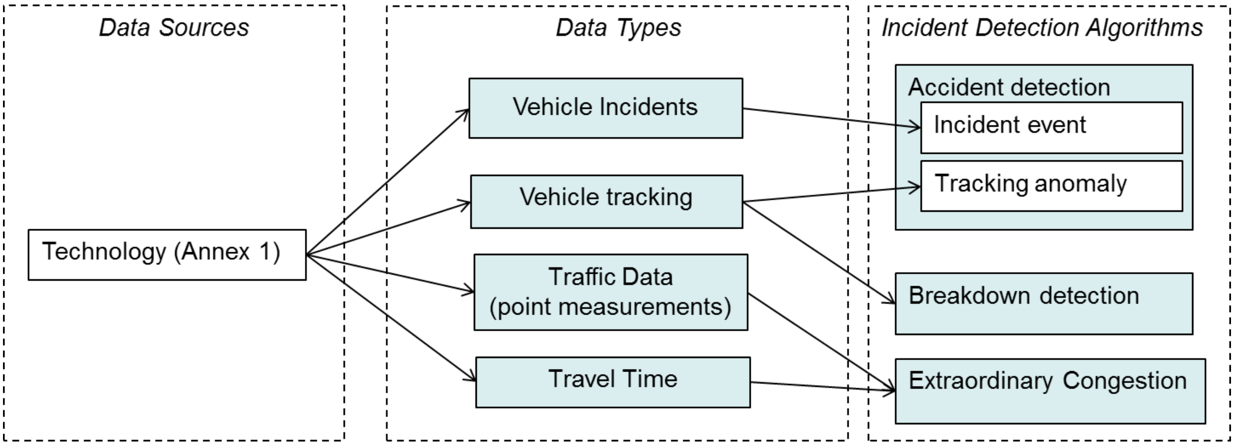


Figure 5: Detection performance model relationships

An incident detection algorithm requires input data of a particular type and quality, which could be provided by different data sources. Vice versa, a data source may also provide data of different type and to different incident detection applications. Figure 6 shows possible combinations for the technologies considered in the library. The thick arrows show the vehicle incidents as direct input for accident and breakdown detections.

Detection performance of data sources can now be expressed in terms of the type of data provided as described section 4. The detection performance of specific incident types can be expressed for the required data types in section 5.

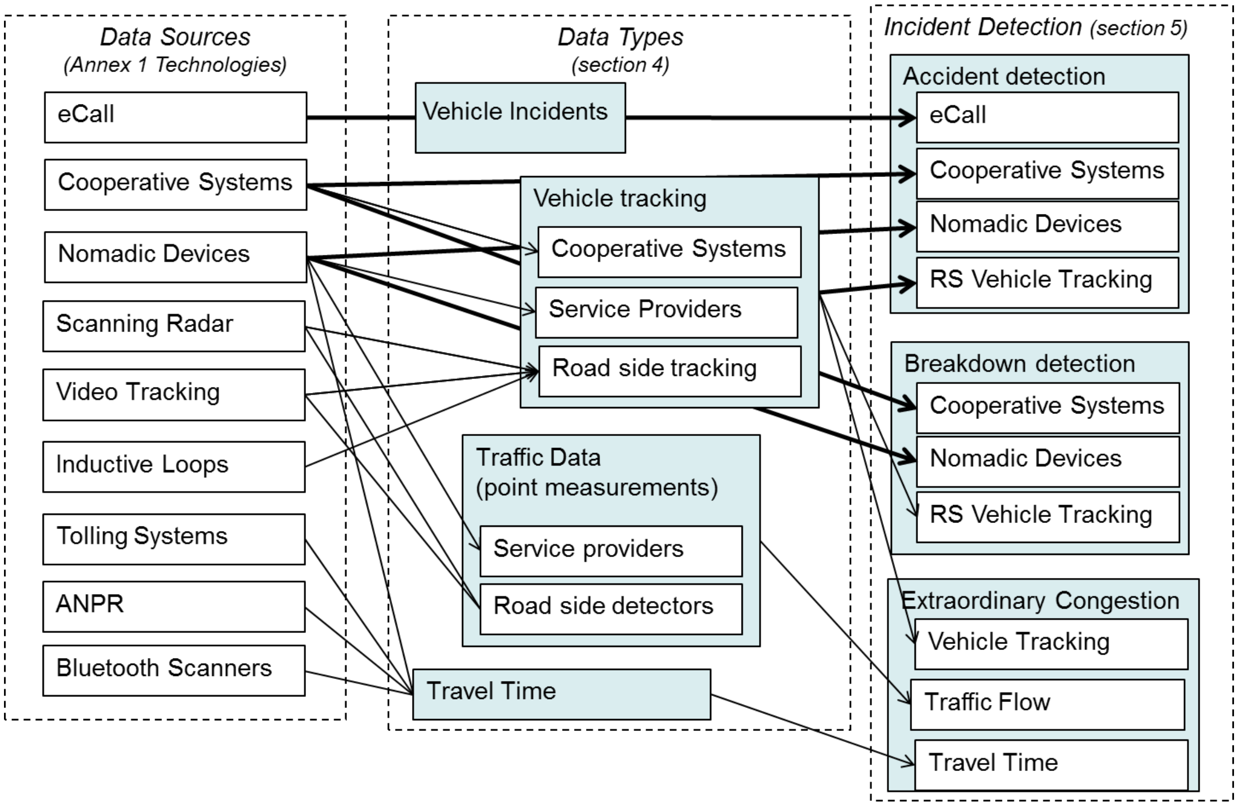


Figure 6: Detection performance model instantiated for technologies

3.4 Cost considerations

Although in this project, full cost-benefit analyses are not performed, it is necessary to give some consideration to the cost elements of each technology and the integration with existing situation. Road authorities are constantly under pressure to achieve optimum value for money in investments, and in recent years budgets have been extremely stretched.

Therefore, the potential costs of each technology assessed are also considered. Since absolute costs are highly dependent on many factors, such as the size of the network, this assessment is made on a relative basis, in comparison to the existing system. This provides the road authority with a simple, high-level indication of the potential impact on costs. For each cost element, the technology will be rated as low, medium or high compared with the existing (reference) system.

	Low	Medium	High	Very High
Costs	€	€€	€€€	€€€€

Three cost elements are considered: setup costs, maintenance costs and operational costs. Some further guidance on developing a business case for an incident detection is provided in Annex 2.

3.4.1 Setup costs

The setup costs are all those associated with the initial set up of the proposed incident detection system. This will include all hardware costs for the physical equipment, e.g. sensors, detector stations or vehicles and any associated software. It will also include costs covering the installation, mounting and calibration of the system – both equipment and manpower. Setup also covers setting up of any necessary communications networks from the roadside to central stations, and detection and operator support systems at central locations.

3.4.2 Maintenance costs

Maintenance costs are those associated with the on-going maintenance of the proposed system. This includes any necessary regular cleaning and calibration. It also includes consideration of the lifetime of the components (both hardware and software) and the cost and regularity of replacements

3.4.3 Operational costs

Operational costs cover all costs associated with the day to day operation of the working system. This includes, for example, manpower costs for validating incidents or data processing, and data provisioning services, e.g. from nomadic devices.

3.4.4 Integration options

A new technology can be integrated into an existing situation in three ways. In Annex 1, the costs of each potential technology are assessed for three generic integration options, notably:

- New system – i.e. there is no existing detection system or infrastructure available, and technology must be installed from scratch. In some cases this may be highly unlikely, however it is important to consider the costs of the system in isolation.
- Retrofitting to existing infrastructure – depending on the technology, there may be existing infrastructure to which the system can be retrofitted, thereby reducing the costs. An example of this could be road side communication network, existing poles, gantries, bridges, lighting columns which could be fitted with new camera technology.
- Upgrading of existing technology – again depending on the technology in question, it may be possible to upgrade the performance of an existing system to improve incident detection at low cost. An example of this could be improved software algorithms for detection or verification or improved communications.

4 Generic Specifications for Data Sources

The technologies from the Technology Library in Annex 1 are considered here as data sources as they provide data for incident detection. Data sources can provide different types of data for incident detection. Some data sources provide incident detections directly, while others provide input to data fusion or algorithms for incident detection for road operators. The technologies are grouped into types of data sources along two dimensions (Table 6):

- The source that acquires the incident related data, i.e. from road side detectors and systems, on-board units, or nomadic devices.
- Type of data that is provided by a data source, i.e. point measurements, travel time, vehicle tracks, vehicle incidents, and road user observations.

Table 6: Types of data sources for road side incident detection

Type of data	*Data source*		
	Road side detector or system	*On-Board Units*	*Nomadic Devices (ND)*
Point measurements	Video, Radar, ILD		ND
Travel time	Video, Radar, ANPR, BT scanners		ND
Vehicle tracks	Video, Radar, RIS	VIS	ND
Vehicle incidents	Video, Radar, RIS	eCall, VIS	
Road user observations			ND

The following subsections characterise the performance of data sources in a generic way. The performance is specified in a generic way in the form of models:

> A model defines a performance criterion for a type of data as a function of characteristics that are specific to a data source, such as the system configuration and environmental effects.

The performance can only be quantified for a specific product in a specific use case, configuration and environmental conditions. As an intermediate step, quantitative performance estimates can be made for data sources in Annex 1 using these models.

The performance measures of data sources are estimated at the interface of the road operator; i.e. where the road operator receives the source data as input to incident detection (section 5). If source data is received via a service provider for example, then the delay in communication and processing through the service provider is included in the detection delay.

4.1 Traffic Data from point measurements

A point measurement is a measurement of a traffic parameter, such as the average speed, traffic density or traffic flow, at a specific location in the road network.

4.1.1 Road side detectors

Road side based point measurement systems are commonly developed to provide traffic data for congestion detection.

Individual vehicle detections

A road side detector such as an inductive loop detector (ILD), a video camera or a radar, provide point measurements of the presence or occupancy of a single vehicle at the time it passes the detector at the fixed location of the detector. The individual road user detections are usually not output by the road side detectors. However, they may be useful for fusion with vehicle-based detections (section 0). The detector performance can be defined by the detection rate DR_{RSP} as the percentage of vehicles that are correctly detected (Table 7). The percentage of vehicles that are missed or otherwise detected incorrectly is ($1 – DR_{RSP}$).

Inductive loop detector stations are proven technology and, when using a pair of well installed and well maintained inductive loops, have excellent performance for vehicle detection; i.e. detection rates above 99% and good classification between cars and heavy goods vehicles (Annex 1.8, Table 7). ILD can be regarded as a benchmark for vehicle detection performance for other detection technologies.

The road side detectors may also provide addition information for every detected vehicle, such as the vehicle speed, vehicle length or class, and vehicle headway. The performance can be expressed as the accuracy with which the vehicle speed, length or class is detected. The vehicle headway is determined as the time difference between subsequent vehicles. The accuracy of headway is directly related to the detection rate DR_{RSP}.

The detection time DT_{RSP} is the time delay between the passage of a vehicle and the detection, which is usually instantly at the road side detector.

Table 7: Performance parameters for individual vehicle detections from road side detectors

Performance criterion	
DR_{RSP}	Detection Rate of road side point measurement of a single passing vehicle
DT_{RSP}	Detection Time of road side point detections of a single passing vehicle

Traffic data

The road side detectors usually aggregate point measurements of individual road user detections to traffic data, e.g. as moving averages of vehicle speeds and flow. The detection accuracy is then defined by the accuracy of the averaged values [14], which is a mathematical abstraction of the individual vehicle detections (Table 8). The accuracy is then determined primarily by the detections of passing vehicles (DR_{RSP}) or rather the missed detections and errors in detections.

When averaging individual detections, the detection time is primarily determined by the time window and communication delay to the node where the incident detection algorithm is running (typically in the traffic control centre). A moving average is characterised by two parameters:

- The sampling time window over which the average of measurements is taken. The time window size determines the sensitivity of the magnitude of detectable incidents. Any perturbations that are smaller than the window size are “smoothed” away. Small perturbations in traffic flow of a few minutes are detected with a time window of 1 minute, but not with a time window of 5 minutes.
- The sampling frequency or sample rate at which the average of measurements is taken, or time step between average measurements.

The time window and sample rate define the upper bound for the possible accuracy and delay for detecting congestion. The minimal delay for detecting congestion is proportional to the time window and sample rate, i.e. an emerging traffic jam can only be detected when the average traffic parameter (flow, speed) over the time window has sufficiently changed in one or more samples. This sensitivity strongly depends on the detection algorithm used (section 5.3.1).

When individual vehicle measurements are averaged over a time window, the accuracy of the averaged traffic data is not very sensitive to the detection rate of individual vehicles. In that case, quality issues with traffic data are more affected by systematic errors in the detection system due to calibration, installation, maintenance, or environmental and weather conditions.

Table 8: Performance parameters for traffic data from road side detectors

Performance criterion	
$DENS_{RS}$	Density or road side detectors (i.e. reciprocal of the detector spacing)
DA_{RSTD}	Detection Accuracy of traffic data (i.e. accuracy of occupancy, flow, average speed)
SW_{RSTD}	Sampling time window or moving window over which traffic data is averaged per sample.
DT_{RSTD}	Detection Time of traffic data is the sampling time.

4.1.2 Services providing traffic data from nomadic devices

A service provider can be a data source for traffic data that is collected and aggregated from nomadic devices. Nomadic devices acquire position and speed information at high frequency for navigation or vehicle tracking on the nomadic device itself (section 4.3.3). These measurements are also sent as Floating Car Data (FCD) to a service provider, typically at a low frequency of one message per 1 to 10 minutes. The device sends aggregated data to the service provider, for example the last sample, the minimum and maximum speeds or the average speed over the last period.

Vehicle-based point measurements provide essentially different traffic data than road side point measurements. Nomadic devices provide:

- measurements from a so-called moving observer viewpoint, whereas road side systems provide measurements from a fixed location.
- measurements evenly distributed along the road, also filling the areas between road side measurement points and roads not covered with road side detection systems.
- location and speed information with an accuracy sufficient for congestion detection (section 5.3).
- sparse measurements from equipped vehicles only. The detection rate of vehicle speeds, for example, is equivalent to the penetration rate of equipped vehicles (PEV_{ND}). Traffic data, like average speeds, flow and densities can only be estimated by extrapolation of this data, which is in accurate at low PEV_{ND}.

Here it is assumed that the road operator is either the service provider or acquires the data from the third party service provider.

Floating Car Data

The detections of location and speed from individual nomadic devices could be used as Floating Car Data (FCD) directly for incident detection or vehicle tracking (see section 4.3.3).For incident, a device sends the FCD with lower frequency to the back office, e.g. once every 1, 2 or 10 minutes and this data is treated as an anonymous point measurement. For vehicle tracking, the update frequency is usually higher, and the device identifier is used to tack the vehicle over time. Table 9 shows the relevant performance parameters for FCD.

Table 9: Performance parameters of Floating Car Data from nomadic devices

Performance criterion		*Estimate*
PEV_{FCD}	Penetration rate of nomadic devices used for positioning and tracking	5%
DR_{FCD}	Detection Rate of positioning and tracking by nomadic devices	$\approx PEV_{FCD}$
DT_{FCD}	Detection Time or update time of FCD	> 1 min
LA_{ND}	Location accuracy of positioning and tracking by nomadic devices	+/- 5 m

Traffic data

Usually a third party service provider would not provide individual device detections but aggregated traffic data (Table 10) or travel time data (section 0). The performance criteria for traffic data are similar to the road side traffic data, aggregated

Detection delays are determined by the communication frequency of the nomadic devices, the data processing by service providers and the provisioning to road operators. Detection delays (DT_{SP}) typically for current services are in the order of DT_{SP} = 3 minutes or more (Annex 1.3).

Table 10: Performance criteria for traffic data from services using nomadic devices

Performance criterion	
PEV_{SP}	Penetration rate of nomadic devices used for a traffic data service
LA_{SPTD}	Location Accuracy of traffic data, which equals the road segment length for which averaged traffic data is provided
DA_{SPTD}	Detection accuracy of traffic data (i.e. accuracy of occupancy flow, average speed)
DT_{SPTD}	Detection Time of traffic data from service provider, which is the sample time at which the service provider sends updates of traffic data

4.2 Travel Time data

There are different methods to estimate travel times; road side travel time estimation from fixed start and end points on a road section, and integration from vehicle tracks or from Floating Car Data. Vehicle tracking systems and FCD services can also provide more accurate and direct congestion detections than via travel times and will not be considered here. If necessary the performance parameters from Table 11 could also be estimated for these sources.

4.2.1 Road side travel time estimation

The data sources are road side technologies that provide travel time measurements from individual vehicles. Travel time measurements can be used for congestion detection. Examples of road side technologies are ANPR, Bluetooth detectors and tolling systems. The measurement principle is to detect and identify a specific vehicle at two locations. The travel time is the time difference between the detections at the two locations.

Travel time can only be measured when a vehicle is unambiguously detected at both locations. If the vehicle was missed at any of the two locations, the travel time cannot be determined. The detection rate DR_{TT} is defined as the percentage of correctly identified vehicles at the two locations from which the travel time can be determined.

Travel times can be used for congestion detection only if the incident causes a significant delay in traffic, such as a capacity drop in traffic flow due to a traffic jam or when a road is (partially) blocked due to an accident or stranded vehicle. In low volume traffic, the travel time delay may even remain undetected as traffic can bypass the accident without significant delay.

The location of the incident cannot be identified from the travel time delay. The distances between measurement locations ($DIST_{TT}$) are typically in the order of several kilometres. The accuracy of the location of the incident is therefore poor; i.e. equivalent to the distance between the detection locations.

The averaged travel times are not very sensitive to the number of missed vehicle detections. Hence moderate detection rates of individual vehicles (DR_{TT}) are acceptable for congestion detection, and only medium to high levels of congestion can be detected.

Variations in travel time are inherent due to differences in vehicle classes and driving styles. These variations increase over longer routes. This means that travel time estimates should be averaged over many vehicles (see section 4.1.1), which implies further delay in detection time of an incident. The estimates are sensitive to momentary distributions of vehicle class and driving styles, two factors that may also vary significantly over time (e.g. rush hour or middle of the day, mornings and evenings, Sundays or working days, during events).

The cause of the incident cannot be identified from the detections or travel time. When an incident occurs somewhere on the monitored road segment, then the travel time delay can only be detected when the involved vehicles should have arrived at the end location. The minimum detection delay is determined by the undisturbed average speed and the distance of the incident location to the end location. An incident near the end of the segment could be detected earlier than an incident near the beginning of the segment. The variation in detection delay however is significant. For a road segment of 10 km with normal free flow speed variations between 70 (V_{min}) and 140 km/h (V_{max}), the free flow travel times vary between 4.3 (TT_{min}) and 8.6 (TT_{max}) minutes. The normal variation in travel time is then 4.3 minutes. Detection time (DR_{TT}) is by definition larger than the maximum normal travel time (e.g. larger than 8.6 min) and increased by some excess time.

Table 11: Performance parameters of road side travel time measurement systems

Performance criterion		*Equation*
$DIST_{TT}$	Distance between detector locations	
V_{min}	Free flow minimum vehicle speed	
V_{max}	Free flow maximum vehicle speed	
TT_{min}	Free flow minimum travel time	$DIST_{TT} / V_{max}$
TT_{max}	Free flow maximum travel time	$DIST_{TT} / V_{min}$
ΔTT	Travel time variation in free flow	$TT_{max} - TT_{min}$
DR_{TT}	Detection Rate of vehicles identified at begin and end location	
DT_{TT}	Detection Time of travel time delays	$> TT_{max}$
LA_{TT}	Location accuracy of incident	$DIST_{TT}$

Travel time data is not a useful data source for the detection of accidents or broken down vehicles. When a missed vehicle would be classified as an accident or break down, the false alarm rate would be unacceptably high, even at very high detection rates.

4.3 Vehicle tracking

Vehicle tracking sensors detect and track one or more vehicles over a period of time. In-vehicle positioning systems and nomadic devices continuously track only the host vehicle in which they reside. Road side detectors, such as video, radar or laser scanners, track all vehicles in range of view of the sensor.

The performance of vehicle tracking data sources is specified in Table 12. To detect sudden anomalies in a vehicle track, e.g. during an accident or while manoeuvring to a refuge area, the sampling frequency, detection latency or delay, and location accuracy should be sufficiently high (see sections 5.1.4 and 5.2.3).

The relevant system configuration is defined by the penetration rates of equipped (host) vehicles or the density of road side equipment. Vehicle tracking does not generate events or alarms, so there is no FAR specified.

Table 12: Performance parameters of vehicle tracking data sources

Performance criterion	
DENS	Density of road side equipment
PEV	Penetration rate of equipped vehicles
DR	Detection Rate of the percentage of vehicles that are tracked
DT	Detection Time of vehicle positions or track updates
DF	Detection or sampling frequency of vehicle positions or track updates
LA	Location accuracy of vehicle position and track

4.3.1 Road side vehicle tracking systems

Road side sensors, such as video cameras, radar or laser scanners have a limited range of view and cover a relatively small longitudinal and lateral area of the road in which vehicles can be detected and tracked (see Annex 1.5). The functionality to detect and track individual vehicles, or other road users, is realized by the signal processing software of the detector systems. In each frame or scan, vehicles are detected. A vehicle is tracked over a series of successive frames or scans by associating detections from successive frames to the same vehicle. The series of detections result in a trajectory of positions per vehicle, from which the momentary speed can be derived. The road side sensors scan with high frequency, resulting in trajectories with a sampling frequency similar to in-vehicle tracking systems.

The different sensor systems use some form of signal processing on the video frames or scans from the sensor. Vehicles can only be detected and tracked while they are in sight of the sensor. Occlusion is the major reason for detection and tracking errors and reduced detection rates. Occlusion occurs when the target object is occluded by another nearby object. Occlusion increases when the separation distances between vehicles decrease; i.e. in denser traffic. Video, radar and laser tracking systems suffer from occlusion, albeit in different ways.

The effective detection area is the lateral and longitudinal distance from the sensor in which vehicles can be detected and tracked without significant degradation due to occlusion. This detection area is determined by a number of system configuration parameters. The detection area is determined by the sensor mounting; e.g. the lateral location on the road and installation height. It can be assumed that the sensor mounting is optimised for the incident detection class and the spacing or density of sensors. The detector density ($DENS_{RST}$) is the number of sensors per road length, or the inverse of the sensor distance.

When the detection area reduces and becomes smaller than the spacing of the sensors, the detection rate of vehicle tracking (DR_{RST}) decreases proportionally. The detection rate depends on the detector density, traffic density or volume, and weather conditions.

If an object is temporarily occluded, the initial track is lost, and a new trajectory will be created once the object is in view again; i.e. the vehicle trajectory gets defragmented. Defragmentation of tracks seriously affects the performance of detection of accidents or stationary vehicles. Tracking algorithms can be used to predict the motion state of occluded (lost) vehicles for a short period of time to alleviate this problem to some extent, especially in low density traffic. In high density traffic, the effective detection range and detection rate will be reduced more though.

Weather and other environmental conditions may further degrade the detection range and detection rates (accuracy) of vehicles. Video systems use visible light and the performance will be negatively affected by weather conditions deteriorating the visibility, such as shades, fog, heavy rain and snow. Laser scanners will be affected in a similar way. Radar detectors and scanners may be less sensitive to weather conditions, depending on the radar frequency. On the other hand, radar systems are sensitive to reflections of the radar signals on neighbouring objects and dispersion of the radar signals due to form and shape of vehicles.

The time delay in the detection and tracking of vehicles depends on the sensor and tracking sampling frequency and is very small. The accuracy for locating a vehicle depends on detection range and reduces with the detector density.

4.3.2 Cooperative Systems

Cooperative vehicles with a Vehicle ITS Stations (VIS) are a data source providing motion state data from the host vehicle in Cooperative Awareness Messages (CAM) (see Annex 1.2.2). This information can be used for vehicle tracking by road operators. The performance specifications for Table 12 are taken from Table 40 and summarized in Table 13 and Table 14. In Annex 1.2 two system configurations are defined:

1. Configuration in which VIS communicate with RIS via ITS G5 short range communication. This information can directly be used for vehicle tracking at the RIS. This option requires a certain density of road side units with a RIS ($DENS_{RIS}$). The performance specifications are summarized in Table 13.
2. Configuration in which the VIS communicates via 3G and provides the vehicle track updates via a service to the road operator. The performance specifications are summarized in Table 14.

As positioning and tracking is the basic functionality of vehicles for maintaining cooperative awareness, the detection rate at the road side is equivalent to the penetration rate of cooperative vehicles. A major disadvantage of cooperative systems is the low penetration rate or vehicles equipped with a VIS (PEV_{V2I}) expected by 2020. This significantly reduces the suitability of the technology by 2020. As with eCall, this drawback is expected to be resolved by 2030.

In-vehicle systems accurately determine the position, speed, acceleration, yaw rate and heading of the host vehicle with frequencies of 1 Hz or higher. Typically a GNSS is used for absolute positioning, of which the performance is comparable to nomadic devices (for standard applications). Higher positioning accuracy is possible with more expensive positioning sensors and systems in the vehicles, but that will only be realized when explicitly required. The location accuracy based on GNSS is assumed to increase over the next years (section 3.2.4). Typically, also inertial navigation systems are used to improve the GNSS positioning and motion tracking over time.

Table 13: Guestimates for VIS vehicle tracking on a road side RIS (configuration 1)

Performance criterion		*Estimate*
PEV_{V2I}	Penetration rate of vehicles equipped with VIS to provide vehicle positioning and tracking information	5%
$DENS_{RST}$	Density of RIS for vehicle positioning and tracking	1.0 RIS/km
DR_{RST}	Detection Rate of vehicle positioning and tracking	5 %
DT_{RST}	Detection Time of vehicle positioning and tracking	< 1 sec
DF_{RST}	Detection frequency	10 Hz
LA_{RST}	Location accuracy of vehicle positioning and tracking	+/- 1.0 m

Table 14: Guestimates for VIS vehicle tracking via 3G (configuration 2)

Performance criterion		*Estimate*
PEV_{V2I}	Penetration rate of vehicles equipped with VIS to provide vehicle positioning and tracking information	5%
DR_{RST}	Detection Rate of vehicle positioning and tracking	5 %
DT_{RST}	Detection Time of vehicle positioning and tracking	> 10 sec
DF_{RST}	Detection frequency	< 0.1 Hz
LA_{RST}	Location accuracy of vehicle positioning and tracking	+/- 1.0 m

4.3.3 Services providing tracking information from Nomadic Devices

The data source is a service providing tracking information from Nomadic Devices. Nomadic devices determine the position, speed and heading of the host vehicle with frequencies of 1 Hz or higher. Typically a GNSS is used for absolute positioning. The location accuracy based on GNSS is assumed to increase over the next years (section 3.2.4). The overall positioning accuracy of nomadic devices is considered less than for in-vehicle systems. The information can be send via mobile cellular network communication (3.5G or 4G) to service providers (section 4.1.2).

Table 15: Performance parameters of positioning and vehicle tracking from nomadic devices

Performance criterion		*Estimate*
PEV_{NDT}	Penetration rate of nomadic devices used for positioning and tracking	5%
DR_{NDT}	Detection Rate of positioning and tracking by nomadic devices	$\approx PEV_{NDT}$
DT_{NDT}	Detection Time of positioning and tracking by nomadic devices + communication and processing time by the service provider	> 10 sec
DF_{NDT}	Detection Frequency	< 0.1 Hz
LA_{ND}	Location accuracy of positioning and tracking by nomadic devices	+/- 5 m

In contrast to the traffic data service provided (section 4.1.2) the data from nomadic devices should not be sent at a low frequency and should not be aggregated in a back office. Instead this information should be directly forwarded to the road operator.

4.4 Vehicle incidents

Several technologies can be applied to acquire data on incident detections from on-board sensors and systems. This data can directly be used by road operators for incident detection in section 5. Performance specifications and estimates are directly derived from the technology specifications in Annex 1 for:

- Services providing eCall events (Table 36).
- Cooperative Road side ITS Stations for incident detection (Table 39)
- Services providing incident detection from nomadic devices (Table 45, Table 46)

5 Generic Specifications of Incident Detection Systems

This section presents models to specify the incident detection performance of systems using one or more data sources from section 4. Such a model relates the incident detection performance measures to using the performance models from section 4 and Annex 1.

The specifications are defined in a generic way in the form of models that relate system configuration parameters, such as the detector density or penetration rate, to detection performance criteria (section 3.3). The costs can also be expressed in terms of the system configuration parameters (section 3.4).

The system configuration of an existing use case has to be adapted to incorporate a new technology for incident detection. The configuration defines parameters of the existing and new incident detection system, such as the type of sensor technology, mounting and spacing of the sensors, and the algorithms for data fusion and incident detection. When systems are used in vehicles, the system configuration also specifies the type of in-vehicle equipment, V2I communication and the penetration rate of equipped vehicles.

The models are applied to compare the suitability of a technology for a class of incidents in the performance and costs tables in Annex 1. The models also enable to specify system configurations for combining new technologies in existing use cases in section 6.

5.1 Accidents

The main user need for accident detection is to improve the safety of the vehicles and road users that are directly and indirectly involved in the accident. The main user requirements for major and minor accidents is a (very) high detection rate. Also, the detection delay should be low to medium, e.g. within 1 minute, to enable immediate actions for traffic control and rescue and recovery services (section 2.4). If the detection delay would be more than 1 minute, the traffic situation would escalate to congestion on high volume roads. The optimum performance would favour high detection rates of major and minor accidents (Figure 2, Table 2). For major accidents, the detection time should be minimal, while for minor accidents the false alarm rate should be minimal.

In addition, the accident detection should provide information on the class and number of vehicles involved, and accurate location of the accident. The vehicle class, and especially whether heavy goods vehicles are involved, is relevant to assess the severity of the accident and the impact on traffic.

This required information can be provided by eCall, vehicle tracking and cooperative systems within 1 minute. Service providers could provide this information from manual alarms from nomadic devices with a slightly larger delay (Annex 1.1). Table 16 gives an overview of the performance assessments of the technologies from Annex 1.

Cooperative systems can also provide information on the presence of dangerous goods, or the operator has to assess this from video cameras or through voice communication via eCall.

To assess the severity of the accident, information on casualties and injuries is also needed. This information can be provided from direct voice communication with the vehicle occupants, as in eCall or via some nomadic devices, or from accident verification via video cameras by the road operator. The latter implies that video cameras are required in combination with any other road side based or cooperative incident detection system. Since none of the technologies automatically acquire data on casualties and injuries, this is not included in the assessments.

In Table 16 the assessments of the technologies for accident detection are summarized for the estimated performance by 2020. The qualifications and colour coding is defined in section 2.3. This clearly shows that vehicle based technologies (eCall, Cooperative Systems and Nomadic Devices) do not reach a penetration rate sufficient for detecting accidents. Road side vehicle tracking systems are the better option for 2020. Table 17 shows that are the best option for the longer term. By 2030, cooperative systems with road side units (RIS) and short range communication (G5) have reached a penetration rate that could provide a sufficient detection rate for accident detection and outperform the FAR of road side vehicle tracking systems.

Table 16: Performance assessment of technologies for accident detection by 2020

Technology	*DR*	*DT*	*FAR*	*LA*	*Vehicle Class & Dangerous Goods*	*Suitability*
Minimum Requirement (section 2.4)	High	Medium	High	Very High	Both	
eCall	Low	Medium	Low	High	Both	Low
Cooperative Systems configuration 1 (ITS G5 + RIS)	Low	Low	Low	Very High	Both	Low
Cooperative Systems configuration 2 (3G)	Low	Medium	Low	Very High	Both	Low
Nomadic Devices	Medium	High	High	High	No	Medium
Scanning Radar	High	Low	High	Very High	No	High
Video Tracking	High	Low	Medium	Very High	Both*	High

* Vehicle class, Dangerous goods by manual inspection of video

Table 17: Performance assessment of technologies for accident detection by 2030

Technology	*DR*	*DT*	*FAR*	*LA*	*Vehicle Class & Dangerous Goods*	*Suitability*
Minimum Requirement (section 2.4)	High	Medium	High	Very High	Both	
eCall	Medium	Medium	Low	High	Both	Medium
Cooperative Systems configuration 1 (ITS G5 + RIS)	High	Low	Low	Very High	Both	Very High

5.1.1 eCall

eCall is a useful data source for major accident detection if the emergency calls are immediately forwarded to the road operator, including the follow up voice communication to vehicle occupants for accident verification (section 3.2.2). Here we assume that this interface is organised by 2020.

The data source is a service, such as a PSAP, providing the eCall event to the road operator for accident detection information (Annex 1.1). eCall events can be generated automatically from an in-vehicle system or manually by a vehicle occupant. The detection rate, false alarm rate and location accuracy of automatically generated event will be similar to accident events generated by cooperative systems. Manually generated events will be similar to the nomadic devices.

eCall events can be used as is for automatic incident detection and alarming operators. This makes eCall a potentially excellent data source for major accident detection in any use case with a very low detection time and false alarm rate, and excellent location accuracy. The performance specifications are defined in Annex 1.1. This information can directly be used as accident detections by road operators in Table 19.

A practical drawback is the low detection rate due to the low expected penetration rate by 2020. The penetration rate of eCall equipped vehicles PEV_{eCall} is estimated in Annex 1.1 at 10% by 2020. The penetration rate is expected to increase rapidly and by 2030 eCall is an expected to be an excellent system for detecting major accidents.

Another limitation is that eCall does not handle minor accidents, which is about 75% of all accidents (section 2.4) and this strongly reduces the effective detection rate for all accidents, even by 2030 (Annex 1.1). Since the road operator can directly use the eCall events received from a service provider for incident detection, the performance estimates for accident detection are similar to those of the data source (Annex 1.1.1).

The most relevant system configuration parameters are the penetration rate (PEV_{eCall}) and the $MDIR_{eCall}$. Here, it is assumed that the detection rate is the sum of automatic detections of eCall equipped vehicles having an accident with any type of other vehicle and manually generated events of nearby accidents.

The detection delay via the PSAP will be similar to the detection delay of accidents reported via nomadic devices (DT_{NDA}).

Table 18: Accident detection performance of eCall services by 2020

Performance criterion		*Estimation*
PEV_{eCall}	Penetration rate of eCall equipped vehicles	10% (by 2020)
$MDIR_{eCall}$	Manual driver intervention rate for using eCall, in case the host vehicle is not involved in an major accident directly but witnesses and accident	10%
DR_A	$= (PEV_{eCall} + MDIR_{eCall} * (1 – PEV_{eCall})) * F_{major}$	5 %
DT_A	$= DT_{eCall}$	> 1 min
FAR_A	$= 5\% * IR_A * DR_A$	0.012 [FA/year/km] on motorways
		0.005 [FA/year/km] on secondary roads
LA_A	$= LA_{eCall}$	+/- 5 m

5.1.2 Cooperative Systems

Cooperative systems consist of vehicles equipped with Vehicle ITS stations (VIS). The VIS run applications that provide information and warnings about accidents, proactively and also when the accidents have occurred. The data source provides the Distributed Environmental Notification Message (DENM) with accident related information or warnings from cooperative Vehicle ITS Stations (VIS) (Annex 1.2.1). The on-board sensors and systems in vehicles can detect a variety of incidents that are also relevant for incident detection for road operators. On-board (pre)crash sensors and airbag systems detect vehicle collisions for example. The performance specifications are defined in Table 39. This information can directly be used as accident detections by road operators in Table 19.

Two system configurations are defined for using cooperative systems (Annex 1.2):

1. Configuration in which VIS communicate with RIS via ITS G5 short range communication. The RIS provides direct input for accident detection by the road operator. This option requires a certain density of road side units with a RIS ($DENS_{RIS}$).
2. Configuration in which the VIS communicates via 3G and provides the incident information via a service to the road operator.

As positioning and tracking is the basic functionality for cooperative awareness, the detection rate at the road side is equivalent to the penetration rate of cooperative vehicles. A major disadvantage of cooperative systems is the low penetration rate or vehicles equipped with a VIS (PEV_{V2I}) expected by 2020. This significantly reduces the suitability of the technology by 2020. As with eCall, this drawback is expected to be resolved by 2030.

The major advantages of cooperative systems over eCall are that the cooperative applications detect most types of accidents, including minor accidents, and that the risk status is also estimated for proactively informing and warning drivers and road operators.

The on-board sensors and diagnostics for detection of actual collisions are generally available in vehicles and are mature and reliable technologies with a high detection rate and location accuracy of the type and cause of an incident. The detection time and false alarm rate are very low.

Table 19: Guestimates for accident detection performance from VIS by 2020

Performance criterion		*Estimate*
PEV_{V2I}	Penetration rate of vehicles equipped with VIS to provide vehicle positioning and tracking information	5%
$DENS_{RST}$	Density of RIS for vehicle positioning and tracking (configuration 1)	1.0 RIS/km
DR_A	Detection Rate of vehicle accidents ≈ PEV_{V2I}	5%
DT_A	Detection Time of vehicle accidents (configuration 1)	< 1 sec
DT_A	Detection Time of vehicle accidents (configuration 2)	> 10 sec
FAR_A	<< 1 % * IR_A * PEV_{V2I}	
	False Alarm Rate of vehicle accidents on motorways	<< 0.003 FA/Year/km
	False Alarm Rate of vehicle accidents on secondary roads	<< 0.001 FA/Year/km
LA_A	Location accuracy of accident positioning	< +/- 1.0 m

It should be noted that more advanced vehicle systems for active and passive safety applications, such as radar or camera systems to pro-actively detect near collisions and other hazards for collision avoidance and warning systems, are more error prone and have a higher FAR and lower detection rate than the cooperative vehicle systems considered here for detecting collisions and vehicle breakdowns.

5.1.3 Nomadic Devices

Nomadic devices are currently not utilized by road operators for detecting vehicle accidents. However, users of applications like Waze [15] for example manually report accidents from their or other vehicles (Annex 1.3.1). This information could also be provided as a service to road operators, in parallel to eCall information on major accidents.

Table 20 lists estimated figures for the performance of nomadic devices for incident detection. It must be noted that these estimates are generic and depend on future developments in this field. It can be assumed that there will not be one standardized solution in the near future, such as eCall for accidents. Instead, several Smartphone apps are likely to be used, which will vary in their performance for detecting incidents.

The figures are based on the assumption that nomadic devices provide automated but also manual reporting of incidents, similar to eCall. Therefore, the detection rate is assumed with a minimum of 70%, taking into account that automatic accident detection is less robust than eCall. Limited coverage of cellular networks on some areas is also a real issue for accident detection, implying that in these locations the detection rate would be 0. The detection time depends on the reaction time of drivers as well as on the availability of cellular communication, but can be assumed as less than 2 minutes. Given the fact that passengers can manually check a detected incident or report an incident, the FAR is estimated low (max. 5% of the events). Since GNSS accuracy is expected to be improved in future, a location accuracy (LA_{ND}) of less than 5 meters can be achieved.

Nomadic devices may not provide accurate vehicle information, such as the vehicle type and class, whether dangerous goods are transported. Eventhough this information could be requested through the applications, it is unsure whether the input is reliable for incident management.

Table 20: Guestimates for accident detection performance of nomadic devices by 2020

Performance criterion		*Estimate*
PEV_{NDA}	Penetration rate of vehicles equipped with a nomadic device with an accident application	25 %
DR_A	Detection Rate of accidents	70 %
DT_A	Detection Time with cellular network communication via a service provider with priority	< 2 min
FAR_A	$= 5\% * IR_A * DR_{NDA}$	
	False Alarm Rate for accidents on motorways	0.44 FA/Year/km
	False Alarm Rate for accidents on secondary roads	0.18 FA/Year/km
LA_A	Location accuracy of on-board positioning = LA_{ND}	+/- 5.0 m

5.1.4 Road side Vehicle Tracking

Road side systems, such as video tracking, scanning radar and laser scanners, detect and track individual vehicles in range of view of the road side detector. Tracking provides continuous trajectories with the positions and speeds from individual vehicles (section 0). The incident detection algorithm at the road side detects slow moving, colliding and stationary vehicles from these trajectories [16] [17]. Vehicle accidents can be distinguished from breakdowns by differences in the trajectory patterns, decelerations and number of vehicles involved. For detection of accidents from trajectories, the sampling rate of vehicle detections or track updates should be sufficiently high and at least at a high frequency of 1 - 10 Hz.

This data can be provided by road side tracking systems such as video (Annex 1.5.1), scanning radar (Annex 1.4.1), and cooperative road side stations (Annex 1.2.1 with RIS). The major advantage of video or radar tracking systems is that all vehicles are tracked and the detection rate (DR_{RST}) is therefore independent of the penetration rate of cooperative vehicles and nomadic devices. Another advantage is that the detection time (DT_{RST}) is very short and in the order of sub-seconds.

Cooperative RIS provide track updates with similar detection times, but only for the cooperative vehicles. While penetration rates of cooperative vehicles (PEV_{V2I}) remain low, this is insufficient for accident detection. Since cooperative vehicles already detect accidents directly, accident detection via vehicle tracking becomes irrelevant for high PEV_{V2I}. During low penetration rates, the RIS data could be fused with video or radar data to improve tracking and eliminate occlusion of equipped vehicles.

The latency of vehicle track data from nomadic devices or from cooperative vehicles via 3G is too high for accident detection.

When vehicles are detected and tracked with sufficient reliability (certainty) and over a period of time (typically more than a few seconds), then the vehicle trajectories are suitable to detect accidents and break downs. Vehicle detection performance critically depends on the mounting and spacing of sensors, and degrades with occlusion by other objects and environmental conditions. Degraded detection performance primarily degrades the detection rate $DR_{RST.}$

The false alarm rate of the road side incident detection system, as the number of false alarms per km of road length, is the product of the false alarm rate of the individual sensor (FAR_{RST}) and the density of the sensors along the covered road length ($DENS_{RST}$ = number of sensors per km). False alarms typically result from tracking errors and critically depend on the quality of the detection and tracking software, and the mounting and spacing of the sensors. Therefore, FAR_{RST} is a function of the sensor technology and the sensor spacing ($DENS_{RST}$). Tuning of the system configuration is necessary for the detection of accidents and breakdowns. The characteristics and costs of the different detection technologies vary significantly.

The location accuracy of an incident (LA_{RST}) depends on the distance of the accident to the sensor and the detection accuracy of the individual sensor, and is a function of sensor density. Therefore, LA_{RST} is a function of the sensor technology and the sensor spacing ($DENS_{RST}$).

Table 12 gives the equations to compute the detection performance in function of the data source performance of section 0.

5.1.5 Travel time

Detection systems that provide travel time estimates, such as advanced inductive loops (Annex 1.8), Bluetooth detectors (Annex 1.7), ANPR (0) or Tolling systems (0), are not feasible for detection of incidents with individual vehicles such as a broken down vehicles or accidents. Potentially, a vehicle that is involved in an incident between two measurement points can be detected as a vehicle that enters the first measurement point, but does not pass the second point. Travel time estimators are not suitable for several reasons:

- Detection time is equal to the vehicle travel time from the location of the incident to the end point of the travel time detector. Detection time would be in the order of minutes, which is not feasible for accident or broken down vehicle detection.
- The location accuracy is very poor, e.g. “somewhere between the entry and exit measurement point.
- The false alarm rate would be orders of magnitude larger than for the three detection concepts above. Even with very high detection rates, e.g. 98%, then 2% of all vehicles without incidents are already missed by one of two consecutive detectors. If

these 2% of the vehicles were identified as missing vehicles, the false alarm rate would be in the order of tens of alarms per km per day, which is unacceptably high.

5.2 Vehicle Breakdowns

Broken down vehicles cause obstructions in traffic flow and are a risk for secondary accidents. The traffic operator needs to take immediate action if a broken down vehicle provides a risk to traffic on the running lanes. When a vehicle breaks down on a running lane, the impact and severity is similar to the obstruction due to an accident. When a vehicle breaks down on a hard shoulder directly near a running lane, it may impact traffic efficiency significantly, especially for a stranded Heavy Goods Vehicle (HGV).

The main user requirements for automatic breakdown detection are a (very) high detection rate, low to medium detection delay, and the location, class of vehicle, and whether it transports dangerous goods (section 2.5, Table 2). In case the breakdown is on a running lane, or involves a HGV or dangerous goods, the detection delay should be minimal, e.g. within 1 minute, to enable immediate actions for traffic control. If the detection delay would be more than 1 minute, the traffic situation would escalate to congestion on high volume roads. The optimum performance would favour high detection rates for breakdowns on the running lanes or in confined areas (Figure 2). A higher false alarm rate is acceptable for more severe breakdowns, and only become a nuisance to the traffic operator for breakdowns in safe refuge areas.

The required information can be provided by cooperative systems and vehicle tracking within seconds. Service providers could provide this information from manual alarms from nomadic devices within minutes. Table 21 gives an overview of the performance assessments of the technologies from Annex 1.

Table 21: Performance assessment of technologies for breakdown detection by 2020

Technology	DR	DT	LA	Vehicle Class & Dangerous Goods	FAR	Suitability
Minimum Requirement (section 2.5)	High	Medium	High	Very High	Both	
Cooperative Systems configuration 1 (ITS G5 + RIS)	Low	Low	Very High	Both	Low	Low
Cooperative Systems (3G)	Low	Medium	Very High	Both	Low	Low
Nomadic Devices	Medium	High	High	No	High	Medium
Scanning Radar	High	Low	Very High	No	High	High
Video Tracking	High	Low	Very High	*	Medium	High

* Vehicle class, Dangerous goods by manual inspection of video

Table 22: Performance assessment of technologies for breakdown detection by 2030

Technology	*DR*	*DT*	*LA*	*Vehicle Class & Dangerous Goods*	*FAR*	*Suitability*
Minimum Requirement (section 2.5)	High	Medium	High	Very High	Both	
Cooperative Systems configuration 1 (ITS G5 + RIS)	High	Low	Very High	Both	Low	Very High

In Table 21 the assessments of the technologies for breakdown detection are summarized for the estimated performance by 2020. The qualifications and colour coding is defined in section 2.3. The performance of the technologies is similar as for accident detection, except that eCall is no option for breakdown detection. This clearly shows that vehicle based technologies (eCall, Cooperative Systems and Nomadic Devices) do not reach a penetration rate sufficient for detecting accidents. Road side vehicle tracking systems are the better option for 2020. Table 17 shows that are the best option for the longer term. By 2030 cooperative systems with road side units (RIS) and short range communication (G5) have reached a penetration rate that could provide a sufficient detection rate for accident detection and outperform the FAR of road side vehicle tracking systems.

5.2.1 Cooperative Systems

Cooperative systems consist of vehicles equipped with Vehicle ITS stations (VIS). The VIS run applications that provide information and warnings about accidents, proactively and also when the accidents have occurred. The data source provides the Distributed Environmental Notification Message (DENM) with breakdown related information or warnings from cooperative Vehicle ITS Stations (VIS) such as the Car Breakdown Warning (CBW) application (Annex 1.2.1). On-board diagnostics systems detect the most relevant types of malfunctions that result in vehicle breakdowns and stops, such as failures of the engine, steering, brakes, or fuel tank level. This information can directly be used as breakdown detections by road operators. The performance specifications of the data source are defined in Table 39, and the performance of the application are specified in Table 23.

Table 23: Guestimates for breakdown detection performance from VIS by 2020

Performance criterion		*Estimate*
PEV_{V2I}	Penetration rate of vehicles equipped with VIS to provide vehicle positioning and tracking information	5%
$DENS_{RST}$	Density of RIS for vehicle positioning and tracking (configuration 1)	1.0 RIS/km
DR_B	Detection Rate of vehicle breakdowns	5%
DT_B	Detection Time of vehicle breakdowns (configuration 1)	< 1 sec
DT_B	Detection Time of vehicle breakdowns (configuration 2)	> 10 sec
FAR_B	$<< 1\ \% * IR_A * PEV_{V2I}$	
	False Alarm Rate of vehicle breakdowns on motorways	<< 0.007 FA/Year/km
	False Alarm Rate of vehicle breakdowns on secondary roads	<< 0.003 FA/Year/km
LA_B	Location accuracy of breakdown positioning	< +/- 1.0 m

Two system configurations are defined for using cooperative systems (Annex 1.2):

1. Configuration in which VIS communicate with RIS via ITS G5 short range communication. The RIS provides direct input for breakdown detection by the road operator. This option requires a certain density of road side units with a RIS ($DENS_{RIS}$).

2. Configuration in which the VIS communicates via 3G and provides the incident information via a service to the road operator.

As positioning and tracking is the basic functionality for cooperative awareness, the detection rate at the road side is equivalent to the penetration rate of cooperative vehicles. A major disadvantage of cooperative systems is the low penetration rate or vehicles equipped with a VIS (PEV_{V2I}) expected by 2020. This significantly reduces the suitability of the technology by 2020. As with eCall, this drawback is expected to be resolved by 2030.

The on-board sensors and diagnostics for detection of actual malfunctions are generally available in vehicles and are mature and reliable technologies with a high detection rate and detection accuracy of the type and cause of an incident. The detection time and false alarm rate are very low.

5.2.2 Nomadic Devices

Nomadic devices are currently not utilized by road operators for detecting vehicle breakdowns. However, users of applications like Waze [15] for example manually report accidents from their or other vehicles (Annex 1.3.1). Commercial applications also exist that provide recovery services when users report a breakdown. These service providers may not forward this information to road operators though for incident detection. This information could also be provided as a service to road operators, and here we assume that this can be organised by 2020.

Table 24 lists estimated figures for the performance of nomadic devices for manual breakdown detection from Table 46. It must be noted that these estimates are generic and depend on future developments in this field. It can be assumed that there won't be one standardized solution in the near future. Instead, several Smartphone apps are likely to be used, which will vary in their performance for detecting incidents.

Table 24: Guestimates for manual breakdown detection performance of nomadic devices by 2020

Performance criterion		*Estimate*
PEV_{NDB}	Penetration rate of vehicles equipped with a nomadic device with an accident application	25 %
DR_B	Detection Rate of accidents	70 %
DT_B	Detection Time with cellular network communication via a service provider with priority	< 2 min
FAR_B	$= 5\% * IR_B * PEV_{NDB}$	
	False Alarm Rate for breakdowns on motorways	0.98 FA/Year/km
	False Alarm Rate for breakdowns on secondary roads	0.39 FA/Year/km
LA_B	Location accuracy of on-board positioning = LA_{ND}	+/- 5.0 m

The figures are based on the assumption that nomadic devices provide manual reporting of incidents, similar to eCall. Therefore, the detection rate is assumed with a minimum of 70%. The detection time depends on the reaction time of drivers as well as on the availability of cellular communication, but can be assumed as less than 2 minutes. Given the fact that passengers can manually check a detected incident or report an incident, the FAR is estimated low (max. 5% of the events). Since GNSS accuracy is expected to be improved in future, a location accuracy of less than 5 meters can be achieved.

Nomadic devices may not provide accurate vehicle information, such as the vehicle type and class, whether dangerous goods are transported, or a vehicle on fire. However, this information could be requested through the applications.

5.2.3 Road side Vehicle Tracking

Road side systems, such as video tracking, scanning radar and laser scanners, detect and track individual vehicles in range of view of the road side detector. Tracking provides continuous trajectories with the positions and speeds from each individual vehicle at a high frequency of 1 - 10 Hz for example (section 0). The incident detection algorithm at the road side detects slow moving and stationary vehicles from these trajectories [16]. Vehicle breakdowns can be distinguished from accidents by differences in the trajectory patterns, decelerations and number of vehicles involved.

The major advantage of road side tracking systems is that all vehicles are tracked and the detection rate (DR_{RST}) is therefore independent of the penetration rate of cooperative vehicles and nomadic devices. Another advantage is that the detection time (DT_{RST}) is very short and in the order of seconds. The data source performance of section 0 can be directly translated in accident detection performances in Annex 1.

When vehicles are detected and tracked with sufficient reliability (certainty) and over a period of time (typically more than a few seconds), then the vehicle trajectories are suitable to detect accidents and break downs. Vehicle detection performance critically depends on the mounting and spacing of sensors, and degrades with occlusion by other objects and environmental conditions. Degraded detection performance primarily degrades the detection rate $DR_{RST.}$

The false alarm rate of the road side incident detection system, as the number of false alarms per km of road length, is the product of the false alarm rate of the individual sensor (FAR_{RST}) and the density of the sensors along the covered road length ($DENS_{RST}$ = number of sensors per km). False alarms typically result from tracking errors and critically depend on the quality of the detection and tracking software, and the mounting and spacing of the sensors. Therefore, FAR_{RST} is a function of the sensor technology and the sensor spacing ($DENS_{RST}$). Tuning of the system configuration is necessary for the detection of accidents and breakdowns (see Annex 1.4 and Annex 1.5). The characteristics and costs of the different detection technologies vary significantly.

The location accuracy of an incident (LA_{RST}) depends on the distance of the accident to the sensor and the detection accuracy of the individual sensor, and is a function of sensor density. Therefore, LA_{RST} is a function of the sensor technology and the sensor spacing ($DENS_{RST}$).

A disadvantage is that additional road side equipment is necessary and that the coverage of the detection system is limited by the range of the road side sensors. Another disadvantage is the degradation of detection performance, and especially the detection rate (DR_{RST}) due to occlusion and weather conditions (the latter especially for video systems).

The incident detection algorithms of the road side tracking systems can be combined with cooperative road side systems and without adding significant costs. The vehicle motion state data received via I2V communication is similar to vehicle trajectories and can be easily fused to improve the accuracy and reliability of incident detection. Road side vehicle tracking systems run in real time. The detection time is similar to the tracking time (DR_{RST}) and is negligible for alarming the road operator.

5.2.4 Travel time

Detection systems that provide travel time estimates, such as advanced inductive loops (Annex 1.8), Bluetooth detectors (Annex 1.7), ANPR (0) or Tolling systems (0), are not feasible for detection of incidents with individual vehicles such as a broken down vehicles (see also section 5.2.4.

5.3 Extraordinary Congestion

Extraordinary congestion can be differentiated into Automatic Incident Detection (AID), moving jam detection, and congestion and stationary jam detection (section 2.6). The main user need for AID is to reduce the risk of secondary accidents at the tail of a jam. The main user need for jam and congestion detection is to improve traffic efficiency. The main user requirements are a high detection rate (> 80%) and a medium false alarm rate (< 2.5 false alarms / day / km). Lower priority requirements are for a medium to low location accuracy (~100m and < 500m) and a high detection time (1 – 5 minutes, for motorways with high traffic volume) are acceptable. Congestion can be detected from different types of data; traffic data, travel time data, and from vehicle tracking.

Differentiation in three incident sub-classes is needed because not every detection technology can be applied to detect emerging jams, jam tails or moving jams. Especially the detection time and location accuracy of the data source determine their suitability for the automatic incident detection and moving jam detection. Table 25 gives an overview of the suitability of technologies for AID and moving jam detection, with minimum requirements for a DT of 1 min (Medium) and the LA of 100m (Medium). Table 27 gives an overview of the suitability of technologies for detecting congestion and stationary jams, with minimum requirements for a DT of 5 min (High) and a LA of 500 m (Low). All technology options from Table 25 can also be read as suitable options for Table 27. The qualifications and colour coding is defined in section 2.3.

5.3.1 Traffic Data from Existing Detection systems

Automatic Incident Detection (AID) is the detection of congestion emerging shortly after the occurrence of another incident, such as an accident or a broken down vehicle. AID is a safety system with the objective to warn drivers approaching the incident location. AID algorithms use traffic data from road side systems or from service providers (section 4.1). This traffic data are occupancies, average speeds, or traffic flow at fixed points in the road network and acquired at low frequencies, e.g. once per minute.

Road Authorities and operators have decades of experience with traffic and incident management systems using variable message signs and inductive loops, video, radar and other road side based point measurement systems. AID algorithms detect incidents as sudden variations in occupancy, flow or average speeds. Many AID algorithms are described in literature, e.g. [4], [18], [19], [20], [21], [22]. In Europe several alternative algorithms have been developed.

The Motorway Incident Detection and Automatic Signalling (MIDAS) system is deployed on over 900 km of motorway in the UK. Inductive loops are used to collect traffic information and to detection queuing and slow moving traffic. The HIOCC algorithm [21] (and HIOCC2 algorithm [23]) uses an occupancy based algorithm that uses a weighted floating average approach to detect the onset of congestion in advance of other speed or flow based algorithms. An AID system in the Netherlands also uses inductive loops of the MTM system and implements a flow-based algorithm. Evaluation of the system shows a medium detection rate of incidents, a DT of less than 10 minutes, and a FAR of maximum 0.3% of the total generated alarms [24]. In Germany, the AIDA algorithm is used [25] to automatically classify the traffic state and for detecting incidents. It uses point measurements for occupancy, average speed, traffic flow of passenger cars and HGVs. A traffic state model is calibrated for each location and divided into four level-of-service (LOS) realms, i.e., free-flow, congestion-free, synchronised and traffic-jam realms. Boundaries between the realms are defined in parameters like the critical traffic flow, minimum and maximum travelling speeds. An incident warning is triggered for a sudden increase of occupancy rate and a decline of traffic volume at the same time.

Table 25: Performance assessment of technologies for Automatic Incident Detection, moving jam detection, congestion and stationary jam detection by 2020

Technology	*DR*	*FAR*	*DT*	*LA*	*Suitability*
Minimum Requirement (section 2.6)	High	Medium	Medium	Medium	
Road side AID (existing systems)	Medium	Medium	High	Low	Low
Vehicle tracking with Cooperative Systems	High	Medium	High	Medium	Medium
Vehicle tracking with Nomadic Devices	High	Medium	High	Medium	Medium
Scanning Radar	Very High	Medium	Medium	Medium	Very High
Video Tracking	Very High	Medium	Medium	Medium	Very High
Data fusion of traffic data and vehicle tracking	High	Medium	Medium	Medium	High
Cooperative Systems – V2V TJAW	High	Medium	High	Medium	Medium

Table 26: Performance assessment of technologies for Automatic Incident Detection, moving jam detection, congestion and stationary jam detection by 2030

Technology	*DR*	*FAR*	*DT*	*LA*	*Suitability*
Minimum Requirement (section 2.6)	High	Medium	Medium	Medium	
Vehicle tracking with Cooperative Systems	Very High	Medium	Medium	Medium	Very High
Cooperative Systems – V2V TJAW	Very High	Low	Medium	Medium	Very High

Table 27: Performance assessment of technologies for congestion and stationary jam detection.

Technology	*DR*	*FAR*	*DT*	*LA*	*Suitability*
Minimum Requirement (section 2.6)	High	Medium	High	Low	
Road side traffic data (existing systems)	High	Medium	High	Low	High
Service providing traffic data from Nomadic Devices	High	Medium	Very High	Low	Medium
Service providing FCD from Nomadic Devices	High	Medium	Very High	Low	Medium
Service providing travel time data from Nomadic Devices	High	Medium	Very High	Low	Medium
Travel time data from Tolling Systems	High	Low	High*)	Low	High
Travel time data from ANPR	High	Low	High*)	Low	High
Travel time data from Bluetooth detectors	High	Low	High*)	Low	High

*) section length should be limited to about 5 km, otherwise the DT is Low (> 5 min)

In [22] an overview is given of AID performance in operations. Although the quality of the results varies, as different evaluation methods were applied for different algorithms, it gives an indication of the performance of existing inductive loop based detection systems and their variations. Detection rates vary between 49% and 96%, and false alarm rates vary between 0.05% and 1.87% of the total number of generated detections per measurement point, and a DT between 1 to 4 minutes. In [26] response times are reported of more than 8 min on average to detect and warn traffic with AID and more than 11 min by manual operator intervention.

Several factors are identified affecting performance due to the momentary traffic situation:

- Traffic conditions (some algorithms have high FAR for low volume traffic)
- Geometric factors such as grades, lane drops and ramps that affect the traffic models
- Environmental conditions (snow, ice, fog, dry/wet) as it affects traffic condition characteristics in the models
- Severity of incidents
- Detector spacing and location of incident relative to detectors
- Heterogeneity of traffic (i.e. percentage of HVG) on traffic models

One fundamental problem is that AID algorithms detect congestion as anomalies to some predefined model of traffic. The model needs to be calibrated for the local traffic situations. However, the traffic situations continuously change due to the above mentioned factors, resulting in false or missed alarms. One approach is to increase the time window for aggregating the traffic data solves only part of the problem part of the time (section 4.1.1). Most algorithms require occupancy, some also traffic volume and speed. Time intervals for averaging traffic data range from 20 sec to 5 minutes, with update intervals of 1 sec to 1 min. Higher time intervals improve the FAR but also strongly increases DT. Another solution would be to auto-calibrate the algorithms, for example as in [19] or [27].

Another operational problem is the reliability of sensor and detection systems due to environmental conditions or incorrect installation or maintenance. Degraded performance of a sensor system for specific environmental conditions, such as snow, rain or fog, affect detection performance and results in reduced detection rates or increased FAR. Incorrect installation or maintenance cannot be attributed to the detection performance of the technology as such.

A wide range of sensor technologies for acquisition of traffic data are in use as alternatives to inductive loops, such as video, radar, infrared, magnetometers, acoustic and ultrasonic. Although these sensor technologies vary significantly in setup and maintenance costs, and their performance may strongly differ under specific environmental conditions, they basically provide similar traffic data as input to similar incident detection algorithms. Due to the above mentioned fundamental issues with fixed point measurements from the road side, the suitability for AID is qualified as “Medium” in Table 25. No new road side sensor technologies are included in this report that are likely to resolve the fundamental issues mentioned above. The systems are well capable of detecting congestion and stationary jams.

5.3.2 Floating Car Data from Nomadic Devices

Alternatives to road side traffic data from point measurements is to use Floating Car Data from nomadic devices (section 4.1.2). The essential difference is that nomadic devices provide traffic data with a high spatial resolution whereas road side detectors provide data only at fixed points.

Nomadic devices send their location and speed frequently to the back office of a service provider or traffic centre. For Automatic Incident Detection the devices can also send abstract data like their minimum speed or max deceleration over the last sampling period, or send an event upon entering or leaving a congested area. This data can directly be used to estimate a the traffic state and emerging, moving or stationary traffic jams. An added benefit of this system configuration is that the incident warning and speed advice can directly be returned to the nomadic devices.

The essential condition is a sufficient penetration rate in combination with the update frequency for data exchange with the nomadic devices. In theory, a low penetration rate of vehicles equipped with nomadic devices does not necessarily lead to a reduction of the detection rate of congestion and jams but an increase in detection time. Eventually a single devices would enter the congestion.

In [28] an estimate is made that 1 to 2% equipped vehicles is sufficient to detect traffic jams in high volume traffic within 10 minutes. The devices sends FCD every 5 to 10 minutes, and also sends a specific message when entering a congested area. It is assumed that data is received from at least 3 vehicles to provide a reliable detection of congestion. When traffic flow decreases, the required PEV increases proportionally. On low volume motorways, the required penetration rate doubles to 4%, and on arterial roads the required penetration rate increases to 10%.

In [29] devices send FCD when entering or leaving a congested area and update FCD every 4 minutes. A penetration rate of 2% is sufficient to predict traffic jams with a DR of 65% within 20 minutes, and with 85% within 30 minutes.

In [30] a logarithmic relation between penetration rate, detection rate and detection time is estimated, based on a theoretical model:

$$DT \sim \frac{1}{Q}\left(\frac{log(1-DR)}{log(1-PEV)} - 1\right) \qquad \textit{Equation 1}$$

Applying this model, scaled to the results from [29] for the requirements from Table 25, then the DT can be increased from 30 min to 1 min with high DR of 85%, then:

- PEV ≥ 5%, DR = 85%, DT < 10 min
- PEV ≥ 45%, DR = 85%, DT < 1 min

The estimated penetration rate of 5% in 2020 is sufficient for services to provide data for congestion and stationary jams. Currently, the penetration rate of nomadic devices, including smartphones, already exceeds the 45%. However, these devices are not associated with a single service providing the data for AID or detection of moving jams. It could be expected that by 2030 the services are organised in such a way that collectively a penetration rate of 45% or higher can be realized.

5.3.3 Travel Time

There are different methods to estimate travel times; road side travel time estimation from fixed start and end points on a road section, and speed interpolation from vehicle trajectories or from Floating Car Data (section 0). Travel time estimations can be provided from inductive loop detectors, BT scanners, ANPR, Tolling Devices, Nomadic devices, in-vehicle sensors. The performance of these data sources can be characterised by the criteria from Table 11. Table 28 shows the performance of congestion detection based on travel time measurements.

Table 28: Performance parameters for congestion detection from travel time measurements (Table 11)

Performance criterion		*Equation*
DT_C	Detection Time of congestion	$DT_{TT} + 0.5^* \Delta TT$
LA_C	Location accuracy of incident	LA_{TT}

Variations in travel time are inherent due to differences in vehicle classes, driving styles, time of day and day of the week, and environmental conditions. Travel time estimates are sensitive to momentary distributions, and should be averaged and smoothened to detect congestion. The absolute variations in travel times increase over longer routes ($DIST_{TT}$) and with lower volume traffic.

Congestion can be detected from a sudden increase in average travel times. When the congestion resolves, the average travel times decrease back to normal again. The average travel times increase due to a significant congestion anywhere on the section. The congestion is significant if the distribution of travel times has shifted sufficiently from the free flow travel time. As a first estimation of this shift is half the variation in travel times (0.5 ΔTT). For the example from section 0 for a 10 km motorway section this means a minimal delay of 2.15 minutes on a minimal free flow travel time of 4.3 minutes. Congestion of delays shorter than 2.15 minutes cannot be detected. The DT is then estimated at 10.75 minutes. This implies that:

- Emerging congestion, moving jams and minor congestions cannot be detected from travel times.
- The minimum detectable congestion increases with the section length due to the larger variations in normal travel times on longer sections.
- The exact location of the congestion on the road section cannot be determined. This information is only useful for re-routing traffic around the road section, but is insufficient for traffic measures on the section itself, and verification by the operator is necessary.

To meet the requirement for a high detection time (DT < 5 min), the section length should be limited to about 5 km.

As discussed in section 5.3.2 and in [28], [29], [30], the penetration rate of vehicles for which a travel time is determined does not have to be very high in order to detect congestion. For tolling systems for HGVs with a PEV of 10%, and detection times of 10 minutes, will result in a sufficiently high detection rate above 85%.

In [31] and [32] several alternatives for travel time calculation are evaluated. Bluetooth detectors (BT), ANPR and the use tolling system data come out as the most cost effective solutions for an NRA [31]. FCD was also evaluated as a fair alternative although the costs for FCD could not be published in [31]. The quality, and especially the accuracy of travel time measurements, average speeds and delays for FCD, ANPR and BT are comparable. Bluetooth can be regarded as an economical and reliable alternative to ANPR for basic traffic information and congestion detection [32]. Bluetooth devices are easier to deploy and maintain. The performance of Bluetooth however is more susceptible to penetration rate, traffic volume, and the antenna positioning and characteristics.

5.3.4 Vehicle tracking

Section 4.3 identified three data sources that provide vehicle tracking data: road side vehicle tracking systems, cooperative systems and services providing tracking from nomadic devices. All three sources are very well suitable to provide data for automatic incident detection and jam detection.

Vehicle tracking data provides data in the form of tracks of individual vehicles or devices. The length of the track can be limited or fragmented, e.g. due to the road segment covered by road side tracking systems or Road side ITS Stations (RIS). The sampling rate of data points in a track can also differ, for example in 10 Hz from road side tracking systems and RIS, or higher for nomadic devices (e.g. 0.1 Hz or 1 update per minute). In any case, the sampling rate is higher than for the Floating Car Data (section 5.3.2).

Another important distinction with Floating Car Data is that the data points of vehicle tracks are not anonymous, but associated to the individual vehicle or device. Hence, congestion can be detected from vehicle tracks by pattern recognition on vehicle speeds and accelerations. Congestion can be detected as areas where vehicles slow down, drive with low speeds (e.g. < 40 km/h on motorways), as stop and go traffic, or speed up again to normal free flow speeds. Pattern recognition detection algorithms are similar to those for detecting accidents or broken down vehicles (sections 5.1.4 and 5.2.3). However, the patterns of multiple vehicles can also be detected with lower detection rates of tracked vehicles. As presented in section 5.3.2 and in [28], [29], [30], lower penetration rates of 5% (as estimated for PEV_{NDT} and PEV_{V2I}) are sufficient for reliable congestion detection. Due to the higher sampling rate of vehicle tracks, the detection time will be much shorter than for FCD.

5.3.5 Cooperative Systems

One of the basic applications of cooperative systems is the Traffic Jam Ahead Warning (TJAW) [33]. This application can be implemented as an I2V application, in which the road side detects the traffic jam and sends a warning to cooperative vehicles. Here we are addressing the V2V application in which vehicles cooperatively detect traffic jams and warn other vehicles. There are several cooperation schemes described for cooperative or distributed congestion detection using vehicle to vehicle communication only, and without the involvement of the road side ([34], [35], [36], [30]). Cooperative vehicles themselves detect when they enter a traffic jam, based on their own speed, neighbouring traffic situation, and messages received from neighbouring vehicles. There are different strategies and control schemed to determine the traffic state and traffic jam location. Once a traffic jam is confirmed, the vehicles warn other vehicles with TJAW messages.

The penetration rate of equipped vehicles PEV_{V2I} determines the performance of congestion detection. For low penetration rates, multi-hopping communication strategies are being developed and standardized to relay the messages to other vehicles and road side units. For higher penetration rates, communication congestion strategies are being developed to avoid the deterioration of the communication channels.

According to the references, a penetration rate of PEV_{V2I} = 5% is deemed sufficient for reliable jam detection and warning within a detection time of 5 minutes. The PEV affects the detection rate, detection time, accuracy of jam location, and the false alarm rate.

5.3.6 Data Fusion of traffic data and vehicle tracking

An alternative to improve existing detection systems is to fuse the traffic data with other data sources. The Dutch NDW and the German MDM [37] are examples where traffic data is fused with different sources like FCD and travel time data. The setup of such a centralised data warehouse does not support Automatic Incident Detection and moving jam detection.

Alternatively, the traffic data can also be fused by the NRA at the traffic centre with FCD or vehicle tracking data from nomadic devices or cooperative systems. This is an interesting option for existing AID systems during the integration of the other technologies. By 2020 the penetration rates of cooperative vehicles and nomadic devices for vehicle tracking are small (5%) and cannot meet the minimum requirements for AID and moving jam detection as a separate technology. Fusion of these data sources however, significantly improves the spatial and temporal resolution of the traffic data from existing road side detection systems. In [38] it is estimated that the detection time of an emerging congestion can be detected within 1 minute with an accuracy of the tail location of 100-200m.

6 Use Cases

This section shows how the generic specifications enable the selection and assessment of alternative technologies to improve the detection performance in a cost effective way for a specific Use Case.

In total, 36 Use Cases could be considered from section 3.1 by combination of 3 road network types, 2 traffic flow situations and 6 existing systems. Instead a few Use Cases are presented here to demonstrate the process. These 5 Use Cases from Table 29 were selected as the 5 most relevant and common Use Cases for European NRAs.

Table 29: Most relevant Use Cases

Use Case	*Road Network*	*Traffic Volume*	*Existing Systems*
1	Motorway without hard shoulder	High	Inductive loops @ 500m
2	Motorway with hard shoulder	High	Electronic Tolling system
3	Motorway with hard shoulder	Low	-
4	Secondary road	High	-
5	Secondary road	Low	-

The process consists of the following steps:

1. A specific Use Case defines the priorities and requirements for incident detection and the existing situation into which new technologies should be integrated.
2. Alternative technologies are selected that best match the requirements. System configurations are sketched to integrate a technology, or a combination of technologies, into the existing system. The generic specification allow to adapt system configuration parameters to meet the requirements.
3. A quick qualitative assessment of the cost and benefits is made for alternative system configurations.

The qualitative assessment is based on generic specifications of technologies. The outcome is a short list of technologies that are most relevant candidates for a specific Use Case, and serve as a starting point for a more detailed assessment by an NRA.

6.1 *Assessment of emerging technologies*

Several new technology developments are imminent, as discussed in section 3.2, and should be taken into account in some way in all Use Cases. The general assessments on benefits and costs for these technologies can be made upfront.

6.1.1 eCall

eCall will be mandatory in all new vehicles and operational by 2020. The penetration rate is estimated to be PEV_{eCall} = 10% by 2020 and is likely to increase further without additional costs for NRAs. eCall will provide high quality detections of emergencies and major accidents at a relatively small cost for the NRA. The detection quality will be similar to other in-vehicle data from cooperative systems or from more expensive road side systems. Following assessments can be made:

- The detection rate of major accidents is proportional to the penetration rate of equipped vehicles, and is likely to become very high after 2020.
- The false alarm rate for major accidents will be low, as the detections are either generated by the proper in-vehicle systems and filtered by a PSAP.
- The NRA may have to invest to integrate eCall information from the PSAP into the traffic management and control environment. This is an opportunity to make sure that the time delay for data exchange is minimal and that all information relevant to incident management, and not necessarily included in the automatic eCall message, is included. This will have a significant impact on the detection time (DT).
- eCall is only intended for emergencies and can only provide automatic detections of major accidents. Alternative technology will be required.

eCall will work on the entire road network and is a good detection technology in any use case for major accidents, even by 2020 when the penetration rate is still low.

6.1.2 Cooperative systems

Cooperative system have potentially the best overall performance for accidents, breakdown and congestion detection of all technologies considered. The basic set of cooperative applications include accident, breakdown and congestion detection. These events are detected by in-vehicle systems and provide a reliable and high quality data source for incident detection for the NRA, with a very high detection rate for equipped vehicles, low detection times and false alarm rates, and accurate location and vehicle information.

Cooperative systems are not mandatory like eCall and are likely to have a lower penetration rate of $PEV_{V2I} = 5\%$ by 2020. This low penetration rate implies that the detection rate for the NRA cannot meet the requirements by 2020 and other (existing) detection technologies may still be required.

It is likely that the penetration rate will increase after 2020 to similar levels as eCall because new vehicles and aftermarket systems are likely to increase. When the penetration rate is high, cooperative systems can meet the performance requirements for all three incident classes, and no other detection systems would be needed for the three incident classes considered.

The event-based information for the incidents is most likely communicated via ITS G5 WiFi between vehicles. The NRA would have to install new road side units with Road side ITS Stations (RIS) along the motorway sections. There are several implementation strategies possible:

- A conservative estimate of the required density of 1 RIS every 800 – 1000m is used in this report. This density would fully cover the motorway section to communicate to every Vehicle ITS Station directly. This is the most expensive solution taken in this report.
- Alternative communication protocols are being developed and standardised for multi-hopping of event messages and collecting probe vehicle messages. This enables vehicles to store and forward event messages over distances longer than the G5 communication range, and to deliver the event messages when passing a remote RIS. The number of RISs could potentially be reduced significantly within the required detection time of 10 sec or 1 min.

In any case, the setup and maintenance costs for cooperative road side systems are amongst the cheapest road side systems considered. Nevertheless, this system configuration is only relevant when the detection of accidents and breakdowns is required. If only congestion should be detected, other technologies are more cost-effective.

If a road segment is not equipped with road side units, then cooperative vehicles may still communicate events on accidents and breakdowns via cellular networks (3 - 4G) to back offices of service providers or Road authorities. It is not standardised if and how this communication medium should be used for events though. If 3-4G communication will be used, then the NRA could still receive the incident event messages with some additional increase in the detection time for incident detection.

6.1.3 Nomadic Devices

Nomadic devices can provide event data for accidents and breakdowns, and various types of data for congestion detection. The nomadic devices send the data to a back office of a third party service provider of from the NRA. The system configuration is essentially a centralized approach via the cellular network communication and the back office. This is essentially different from the cooperative systems technology:

- The centralized data flow via the cellular network and a back office increases the detection time, which is particularly critical for the detection of accidents and breakdowns.
- The centralized data flow is vulnerable to the communication performance of the cellular network, and communication downtime are not uncommon. The reliability of the system is significantly less than a ITS G5 communication network.
- The setup and maintenance costs for the NRA will be relatively low, because the NRA does not have to install road side units along the road network.

There are a few down sides expected with detection performance:

- Although the penetration rate of the devices is expected to be very high by 2020, the effective penetration rate from which the NRA will receive incident data may be much lower. This is due to the wide variety in applications and service providers a user of a nomadic device can choose from. This effective penetration rate is estimated at 25% for accident and breakdown event data, and at 5% for traffic, travel time and floating car data.
  - For congestion detection, the low PEV may not be an issue.
  - The detection rate (DR) for accident and breakdown detection is proportional to the PEV, which is insufficient.

  The only solution to increase the PEV is to concentrate the data to a single application or service providers, for example through an electronic market or data warehouse. This option is not taken into account here though. Hence, the suitability of the technology is rated as medium to all incident classes.

- Nomadic devices are not directly connected to in-vehicle systems[2] that detect accidents or breakdowns reliably. Instead, these events should be either detected from sensors on the nomadic device, or manually reported of the user. Both solutions will result in higher false alarm rates than the detections from eCall or cooperative vehicle systems.

- The detection time for receiving accident or breakdown detections is high due to the standard communication frequencies and data processing via the service providers. Technical solutions should be used to reduce the detection time to maximum 1 minute to be used for accident and breakdown detection by the NRA.

- Service providers can also provide traffic data, FCD and travel time data. When the effective penetration rates remain low (e.g. 5%), the congestion will be detected, but with increased detection time and decreased location accuracy. A service provider may improve the location accuracy when the penetration rate of devices increases well above 5%.

This makes the nomadic devices particularly suitable in Use Cases with a higher priority on cost minimisation and congestion, and lower priority on accidents and breakdowns.

[2] This is technically possible and considered as a cooperative system in this report.

6.2 Motorway without a hard shoulder, high traffic volume, standard road side equipment

6.2.1 Reference System

The infrastructure in this use case is characterised by a motorway section without a hard shoulder or the hard shoulder is used as an extra lane. The traffic volume is high. The existing road side system consists of a high number of inductive loops locates every 500m and on every lane.

For detecting extraordinary congestion and stationary jams, the existing system has a high detection rate (DR) and medium false alarm rate (FAR) (Table 27). The detection time of a traffic jam is high (DT > 1 min and < 5 min). The initial location of the traffic jam fronts is determined by the loop spacing and can be rated as low. When the jam progresses, estimation algorithms could provide a higher accuracy after some time (LA > 100m). The existing system does not need to be improved for congestion detection, other than replacement with a more cost effective technology by 2020.

The existing system can be used for Automatic Incident Detection as well. Such algorithms cannot detect a vehicle accident or breakdown, but detect and trigger alarms on the congestion caused by the accident or broken down vehicle. The detection time is high and takes more than 1 minute, depending on the location of the initial incident relative to the loop locations.

The existing system also has road side equipment for signalling, such as gantries with matrix signs and CCTV cameras for verification and validation of incidents.

6.2.2 Requirements

The absence of a hard shoulder or refuge area significantly increases the impact on safety, congestion and incident response. Any accident or breakdown will block a running lane and result in immediate congestion and a high risk on secondary incidents.

The desired system should detect accidents and vehicle breakdowns directly and faster than via the AID.

The priority for performance requirements are on a (very) high detection rate (> 90 % and at least > 80%) and low detection time (< 10 sec and at least < 1 min) for accidents and breakdowns.

A medium false alarm rate and additional workload for traffic operators is acceptable.

A high location accuracy is required to distinguish the lane in which the accident occurs. The operator also needs to know the classes of the vehicle(s) of the accident, especially whether a heavy good vehicle or dangerous goods are involved.

The means for immediate verification of incidents is required. Cameras are required along the road segment for immediate verification of incidents unless the operator has other means for verification. Cameras may also be required for ensuring the hard shoulder is clear of obstructions prior to opening as a running lane.

Requirements for congestion detection have a lower priority than for accidents and breakdowns. If any additional technology would still be needed, then the costs will be the primary criterion for selection.

6.2.3 Options for incident detection systems

Table 30: Options for Use Case 1

Option	Technology	Suitability				Costs		
		Accidents	Break downs	AID	Conges-tion	Setup	Maint.	Oper.
1	Inductive Loop Detectors							
	Upgrade for tracking	Low	Low	Low	High	€	No extra costs	
	Fusion of ILD and RS tracking			High				
2	eCall					€	€	€
	2020 (PEV = 10%)	Low*)						
	2030	Medium*)						
3	Nomadic Devices					€	€	€€€/€
	events	Medium	Medium					
	RS vehicle tracking of nomadic devices			*Medium*				
	Traffic Data, FCD, Travel time data				Medium			
4	Cooperative systems							
	Configuration 1 (ITS G5)					€€	€€	0
	2020 (PEV = 5%)	Low	Low	Medium	Medium			
	2030	Very High	Very High	Very High	Very High			
	Configuration 2 (3G)	Low	Low	Medium	Medium	€	€	0
5	Video Tracking (upgrading CCTV system)	High	High	Very High	Very High	€€	No extra costs	
6	Scanning Radar	High	High	Very High	Very High	€€€	€	€€€/€

*) provides only events for major accidents

The assessment includes 6 options with good prospects (Table 30).

A. Accident and Breakdown detection

1. Upgrading the existing system of the inductive loops for tracking vehicles seems a logical option to extend the AID capability. This means to upgrade the detector software with a tracking algorithm for loops without the installation of additional hardware (Annex 1.8). The upgrading costs will be low but cannot reduce the high maintenance costs of the existing system. With an upgrade of the existing loop system tracking of vehicles in the considered sections is possible. However, it is expected that the detection algorithm cannot meet the required detection rate and detection time.

   Installation of additional loops between the existing loops to shorten the distance is not a cost effective solution.

2. eCall is a cost effective technology for detecting major accidents when the penetration rate and detection rate is high (somewhere after 2020, see section 6.1.1). Other solutions will always be required for minor accidents, breakdowns and other incidents.

3. Nomadic devices can provide event data for accidents and breakdowns, and various types of data for congestion detection. The setup and maintenance costs for the NRA

will be relatively low. The detection performance for all three incident types is medium however, as motivated in section 6.1.3. This is mainly because the detection time is medium to high due to the communication via a back office, and because the effective penetration rate is relatively low.

The time delay due to communication via a back office might be alleviated if the NRA sets up a back office instead of using third party services, and by handling accident and breakdown event with higher priority than floating car data.

The effective penetration rate can be increased by concentrating the data from many applications and service providers to one, for example through an electronic market or data warehouse. This option is not taken into account here though.

4. A cooperative system using ITS G5 short range communication has potentially the best overall performance for accidents, breakdown and congestion detection of all technologies considered (section 6.1.2). The detection rate does not meet requirements in 2020 due to the low expected penetration rate of equipped vehicles. The penetration rate is expected to be high enough by 2030 to provide a complete solution for all three incident classes.

   The NRA would have to install cooperative Road side ITS Station (RIS). A conservative estimate of the required density of 1 RIS every 800 – 1000m is used in this report. Alternative communication protocols would allow fewer RISs. The setup and maintenance costs for cooperative road side systems are amongst the cheapest road side systems considered though, provide the best quality incident data, and the most cost-effective technology.

   Cooperative vehicles can also communicate via 3G, 3.5G or 4G to back offices of service providers or traffic centres. It is highly unlikely that the CAM messages, that could be used for vehicle tracking and AID, would be communicated via 3 – 4 G. It is not standardised yet that event messages for accident, breakdown and congestion will be communicated via 3 – 4 G. Potentially, these messages could also be sent by cooperative vehicles to service providers and provided to road operators for incident detection. In this case, the major difference with G5 communication media is the increased detection time.

The emerging technologies for eCall, cooperative systems and nomadic devices can provide a relative inexpensive solution for incident detection, but can only meet the required detection performance after 2020 (e.g. 2030). To provide a complete solution by 2020, the NRA has to install additional road side detection systems. Two options can be suggested in combination with the existing CCTV cameras.

5. The existing CCTV camera system can be upgraded to a video tracking system. This is a cost effective solution to reduce setup costs and would not increase the existing maintenance and operations costs. The image processing software has to be replaced. If the spacing between the CCTV cameras is to larger (i.e. > $DENS_{RST}$) then additional cameras will have to be installed, which will increase the setup costs.

   In this case, additional solutions may be required during adverse weather conditions if the data from eCall, nomadic devices or cooperative systems is insufficient.

6. If the degraded functionality of video tracking under adverse weather conditions cannot be compensated with technologies selected from options 1-4, then the scanning radar provides a good alternative. Scanning radar provides a high detection rate comparable to video tracking under all weather conditions. The FAR of scanning radar is higher than video tracking, but that may be acceptable. In high density traffic, the spacing of scanning radars should be reduced to reduce occlusion. The setup costs would be higher than the upgrade of the video systems. Scanning radar cannot be used for incident verification, but the existing CCTV system provides just that.

B. Congestion detection

The existing loop detection system, in combination with alternatives like the nomadic devices or cooperative systems, provide the required detection performance. No additional detection technologies are needed for AID, jam or congestion detection.

6.2.4 Assessment of system configurations

Upgrading the loop detectors for vehicle tracking seems an obvious first choice. However, this system does not meet the detection rate required in high volume traffic situations (section 5.3.1), and an alternative technology is required. The existing inductive loop detections can be combined and after 2020 gradually replaced by other detection technologies.

The following alternative system configurations can be proposed by combining options that provide cost effective solutions. All options are combined with the existing inductive loop detectors, CCTV system and eCall.

A. Nomadic devices provide a relatively inexpensive solution to improve the detection performance for accidents, breakdowns and AID. The requirements for the detection of accidents and breakdowns are not fully met though; i.e. the detection rate, detection time and false alarm rate.

   Data fusion of vehicle tracking data from nomadic devices can improve the detection performance of automatic incident detection significantly (see section 5.3.6). This would require that the nomadic devices or cooperative vehicles are tracked and that this track data is available to the NRA for fusion with loop data. The costs for the NRA for using nomadic device data is relatively low.

   Nomadic devices, and fusing the track data with existing loop data, would provide the least expensive solution if medium detection performance is acceptable. The detection performance of data from nomadic devices is not expected to improve significantly after 2020 and do not provide a scenario to gradually replace the inductive loops.

B. A replacement strategy can be initiated by introducing cooperative systems in addition to the system configuration of 1. By 2020, the cooperative system will already be operational, and the detection rate will gradually increase with the penetration rate of cooperative vehicles. The inductive loops can gradually be abandoned when the penetration rate of cooperative vehicles reaches 45% (section 5.3) and can replace AID.

   The system configuration requires a higher setup cost for the NRA than option 1. The operational costs will be much smaller though, due to the much lower false alarm rate. Detection performance will improve significantly to option 1; i.e. the detection rate will become higher, the detection time for accidents and breakdowns will be smaller, the incident location can be set to lane level accuracy and relevant vehicle information (vehicle class, dangerous goods) is obtained automatically.

C. The previous configurations will not provide the required detection performance by 2020. The only remaining option to realize the detection performance for accidents and breakdowns by 2020 is to install road side detection systems for vehicle tracking.
   a. The least expensive configuration is to upgrade the existing CCTV systems for video tracking. This configuration cannot provide the performance under adverse weather conditions when the detection rate of video systems degrade.
   b. Alternatively, scanning radar systems can be installed along the motorway section. The CCTV cameras remain in use for incident verification.

   This configuration makes the inductive loops redundant.

6.3 Motorway with a hard shoulder, high traffic volume, existing tolling system

6.3.1 Reference System

The infrastructure in this use case is characterised by a motorway with a hard shoulder and an existing electronic tolling system (ETS). The traffic volume is high. The ETS operates fully automated with toll gantries between on/off ramps (coverage 100%). To ensure operation and enforcement of the ETS, the system consists of video for visual control. The video system allows manual visual incident detection (with full coverage of considered section).

Costs for maintenance are considered as high, with respect to very high number of hardware elements. Operational costs are considered high as well, due to the continuous need for monitoring for incidents on the video cameras.

6.3.2 Requirements

The following requirement sets could be defined by an NRA:

A. Automation of the congestion detection.

B. Automation of the accident, breakdown, AID and congestion detection.

C. The objective is to reduce the maintenance and operations costs of the video system for visual control. The condition is that a similar incident detection and verification capability is provided. Manual use of video cameras will result in the detection of most incidents after some time, especially due to the emerging congestion. The detection performance required of a new system for congestion is:

    - Medium detection rate,
    - High detection time,
    - Medium location accuracy,
    - Medium false alarm rate.

   The chance of an operator detecting an accident or breakdown within 1 minute is small, so there is no requirement for the performance of accident and breakdown detection.

6.3.3 Options for incident detection systems

The technology assessment includes 7 options with potentially good prospects (Table 31).

1. The existing tolling system can be upgraded for travel time estimation and congestion detection (section 5.3.3). The setup costs will be limited to adding the detection algorithm to use the data from the tolling system. The detection time (DT) is proportional with the length of the tolling section.
2. If the tolling section is longer than 5 km, then additional measurement points for travel time estimation should be installed. Bluetooth detectors are a cost effective solution for congestion detection. BT detectors can be installed as a retrofit near the existing video camera systems, and make use of the existing poles, power and communication network. The setup and maintenance costs for BT detectors are smaller than for tolling systems or ANPR.
3. Upgrading the existing video system means adding image processing software to the video control software in the control centre or road side stations. Alternatively the existing cameras should be replaced by cameras with on-board image processing. The setup costs for upgrading are estimated to be higher than for upgrading the tolling system, and similar to retrofitting scanning radars along the tolling section.

   Video tracking is a suitable solution for automating accident, breakdown, AID and congestion detection (section 5.3.4). However, is does not change the maintenance and operations costs for requirements A.

4. The motivation for eCall is similar to options 2 in section 6.2.3 and section 6.1.1.

5. Cooperative Systems also provide high quality incident detection information and requires minimum maintenance and operations costs for the NRA (section 6.1.2). Especially configuration 2 with 3-4G communication is an interesting option as it requires the least setup costs for the NRA, and still provides a good solution for AID and congestion detection to satisfy requirement B.

   Configuration 1 provides a solution that eventually could satisfy all three requirements and provide an alternative for verification; i.e. it could remove the immediate need for verification of the three classes of incidents considered. This options does require the installation of road side systems though.

6. Services for traffic data, FCD and travel time based on nomadic devices provides an alternative to improve the congestion detection (sections 5.3.2 and 5.3.3). The accuracy of the congestion detection would be higher than for travel time estimation from tolling system data of from Bluetooth detectors (options 1 and 2), but the detection time may be higher when a third party service provider is in the middle. The costs for the NRA to receive data from these services or directly from nomadic devices is relatively small.

   Nomadic devices can provide event data for accidents and breakdowns. The detection performance is medium however as motivated in section 6.1.3, because of the low effective penetration rate, medium detection time, false alarm rate and location accuracy.

   The time delay due to communication via a back office might be alleviated if the NRA sets up a back office instead of using third party services, and by handling accident and breakdown event with higher priority than floating car data.

   The effective penetration rate can be increased by concentrating the data from many applications and service providers to one, for example through an electronic market or data warehouse. This option is not taken into account here though.

7. Scanning radar could be retrofitted to reuse the infrastructure of the existing video surveillance system. Scanning radar provides the detection performance for all three classes of incidents comparable to option 1, with the advantages that the scanning radar system is insensitive to adverse weather conditions, and requires less maintenance than video systems. On the other hand, scanning radar has a high false alarm rate that may not be acceptable, and in high volume traffic, the spacing of the radar scanners should be reduced to avoid occlusion. The setup costs would be higher than the upgrade of the video systems. Scanning radar cannot be used for incident verification, but the existing CCTV system provides just that.

Table 31: Options for Use Case 2

Option	Technology	Suitability: Accidents	Suitability: Break downs	Suitability: AID	Suitability: Conges-tion	Costs: Setup	Costs: Maint.	Costs: Oper.
1	Tolling Systems upgrading				*High**)	€	No extra costs	
2	Bluetooth detectors retrofitting				*High**)	€	€	€
3	Video Tracking upgrading	*High*	*High*	*Very High*	*Very High*	€€	No extra costs	
4	eCall					€	€	€
	2020 (PEV = 10%)	Low**)						
	2030	Medium**)						
5	Cooperative systems							
	Configuration 2 (3G)	*Low*	*Low*	*Medium*	*Medium*	€	€	0
	Configuration 1 (ITS G5)					€€	€€	0
	2020 (PEV = 5%)	*Low*	*Low*	*Medium*	*Medium*			
	2030	Very High	Very High	*Very High*	*Very High*			
6	Nomadic Devices					€	€	
	Traffic Data, FCD, Travel time data				*Medium*			€
	RS vehicle tracking of nomadic devices			*Medium*				€
	Events	*Medium*	*Medium*					€€€
7	Scanning Radar retrofitting	*High*	*High*	*Very High*	*Very High*	€€	€	€€€/€

*) Suitability degrades to Medium if the tolling section is longer than 5 km.
**) provides only events for major accidents

6.3.4 Assessment of system configurations

The following alternative system configurations can be proposed by combining options that provide cost effective solutions. All options are combined with eCall. Upgrading the existing tolling system or video system is not always necessary.

A. Automating congestion detection

1. A service providing traffic data, FCD or travel time data from Nomadic is the most cost efficient solution. The congestion detection performance is medium, as required, and the setup costs and maintenance for the NRA are minimal.
2. If congestion detection is required with a high detection performance (better than with nomadic devices), then upgrading the tolling systems for congestion detection and potentially adding Bluetooth detectors on the tolling section (options 1 and 2) provides the most cost efficient solution.

B. Automating accident, breakdown, AID and congestion detection

3. Option 1 can be extended for handling accident and breakdown events from nomadic devices. The detection performance for accidents and breakdowns is estimated as medium and would require verification using the existing video system.

4. If a high detection performance is required by 2020 for all incident classes, then upgrading the existing video systems for video tracking is the most cost efficient solution. Alternatively, a scanning radar system could be installed instead of upgrading the video systems. The costs and detection performance of options (3 and 7) are similar, and more detailed cost and benefit analysis is required to make this choice.
5. A combination of eCall, Nomadic Devices and Cooperative Systems provides a solution for 2020 and a migration path to reduce the maintenance and operational costs.
   - Till 2020, the Nomadic Devices and the Cooperative Systems provide the detection performance of option 3 and also provide AID.
   - When the penetration rate of cooperative vehicles with G5 communication increases, detection performance will increase and the existing video system can be taken out of service to reduce maintenance and operations costs.

C. Reducing the costs for maintenance and operations

The major cost for maintenance and operations is the video surveillance system. The critical decision to make is whether the verification capability of incidents should be provided or not.

6. Both maintenance and operations costs can be reduced by a combination of eCall and Cooperative Systems and taking the video system out of service. This option will only provide the required performance when the penetration rate is high. It is expected that this will only be realized after 2020, so before 2020 this is not a full solution.
7. Operations costs can be reduced by automating the incident detection. The video system is still needed, e.g. for verification, so the maintenance costs cannot be reduced. There are three possibilities:
   - If detection should include accidents, breakdowns, and congestion, and a medium detection performance is acceptable, then the Nomadic Devices solution (configuration 3) provides the most cost efficient solution.
   - If only congestion detection is required, with a high detection performance (better than with nomadic devices), then upgrading the tolling systems for congestion detection and potentially adding Bluetooth detectors on the tolling section (configuration 2) provides the most cost efficient solution.
   - If a high detection performance is required by 2020 for all incident classes, then upgrading the existing video systems for video tracking, or retrofitting a scanning radar system (configuration 4) is the most cost efficient solution.
8. Maintenance costs can be reduced by taking the video system out of service and provide alternative technologies for automating incident detection. All alternative technologies, that could provide the required detection performance by 2020, need incident verification. Taking the video system out of service implies a significant increase in the costs for operations for alternative incident verification solutions, such as the use of mobile phones or employing service teams. The same three possibilities for configuration 7 from above apply here.

6.4 Motorway with a hard shoulder, low traffic volume, no existing road side equipment

6.4.1 Reference System

The infrastructure in this Case Study is characterised by motorway section without a hard shoulder. The traffic volume is low. The system has no incident detection available and the infrastructure is currently not prepared to add road side equipment easily, i.e. there are no power supply or cable paths available, nor any poles or gantries.

6.4.2 Requirements

In low volume traffic, the number of accidents and breakdowns per km of motorway will be smaller than in high volume traffic and the impact on traffic throughput will also be much smaller. The benefits for expensive road side detection systems are therefore much smaller compared to the costs than in high volume traffic. The most expensive road side detection systems are therefore not considered.

The following requirement sets could be defined by an NRA:

A. Automatic detection of accidents and breakdowns.

   When an accident occurs or a vehicle breaks down, safety is the major risk. In low traffic volume, it is unlikely that congestion will occur, and approaching traffic will not be slowed down. The risk of secondary accidents is high and potentially severe due to the high speeds of approaching vehicles.

   The traffic operator has no means to warn approaching traffic such as variable message signs, and the only possible response is to direct emergency services to the location. The operator has no video system to verify the incident. It is therefore important to automatically detect whether the incident blocks a running lane or whether heavy goods vehicles are involved.

   The following detection performance requirements can be defined in order of priority:

   1. Detection rate should be high as a minimum and preferably very high
   2. To assess the severity of the incident:
      - Location accuracy should be very high to distinguish incidents on running lanes from incidents on hard shoulders and refuge areas.
      - The vehicle class should be known to distinguish HGVs, and whether dangerous goods are transported.
   3. False alarm Rate should be medium
   4. Detection time can be high and be compromised in favour of detection rate and accuracy.

B. Automation of the congestion detection

   The NRA has no means of detecting extraordinary congestion. If automatic detection of accidents, breakdowns and other smaller incidents is not viable, then the detection of extraordinary congestion is an alternative to improve safety.

6.4.3 Options for incident detection systems

The technology assessment includes 5 options with potentially good prospects (Table 32). Due to the low traffic volume Automatic Incident Detection may not work properly and is not considered an option. Due to the low effective penetration rates of nomadic devices and cooperative systems, vehicle tracking may not work very well or the detection delays will increase considerably (section 5.3.2). The motivations for options 1 – 3 are similar to options 2 – 4 in section 6.2.3 and in section 6.1 respectively.

4. Bluetooth detectors are a cost effective solution for congestion detection. The detection performance for congestion is higher than for services based on nomadic devices if the distance between BT detectors is not too long (e.g. about 5 km). Otherwise, the detection delay of congestion increases and performance becomes comparable to third party services based on nomadic devices. The setup and maintenance costs for BT detectors are smaller than for tolling systems or ANPR. BT detectors can be installed easily at the road side and can use wireless communicate to a road side station or control centre.

   The detection time is not a critical requirement and Bluetooth detectors can be installed at strategic points on the motorway section, without limitation of the detector spacing, e.g. near locations where electric power is available.

5. If options 1 – 3 do not provide sufficient performance for detecting accidents and breakdowns by 2020, then the only alternative is to install road side detection systems. The most cost efficient option is to install scanning radar systems at distances of 500m. The false alarm rate may be higher than required. The installation is relatively easy and do not require gantries or large poles, and wireless communication can be used for data exchange to the traffic centre.

Table 32: Options for Use Case 3

Option	Technology	Suitability			Costs for a new system		
		Accidents	Breakdowns	Congestion	Setup	Maint.	Oper.
1	eCall				€	€	€
	2020 (PEV = 10%)	Low*)					
	2030	Medium*)					
2	Nomadic Devices				€	€	
	Events	*Medium*	*Medium*				€€€
	Traffic Data, FCD, Travel time data			*Medium*			€
3	Cooperative systems						
	Configuration 1 (ITS G5)				€€	€€	0
	2020 (PEV = 5%)	*Low*	*Low*	*Medium***)			
	2030	Very High	Very High	*Very High***)			
	Configuration 2 (3G)	*Low*	*Low*	*Medium***)	€	€	0
4	Bluetooth detectors			*High*	€€	€	€
5	Scanning Radar	*High*	*High*	*Very High*	€€€	€	€€€/€

*) Provides only events for major accidents
**) Congestion detection primarily through event detection like Traffic Jam Ahead Warning

6.4.4 Assessment of system configurations

The following alternative system configurations can be proposed by combining options that provide cost effective solutions.

A. Automating accident and breakdown detection

All options are combined with eCall.

1. Services based on nomadic devices provide a solution with medium detection performance for the least costs. The detection rate, accuracy and false alarm rate do

not meet the minimum performance requirements though. This option is similar to option 3 in section 6.3.3.

2. Scanning radar systems provide high detection performance that meet the minimum requirements by 2020. This is also the most expensive option as it requires road side detectors along the motorway section. This option is similar to option 4 in section 6.3.3.
3. Cooperative systems provide the most cost efficient and best performing solution after 2020, but do not provide a feasible solution by 2020.

B. Automating congestion detection

4. Bluetooth detectors are the most cost efficient solution to congestion detection when there is no existing infrastructure. The detection time is not a critical requirement, which means that Bluetooth detectors can be installed at strategic points on the motorway section and with larger distances than 5 km. The detection performance will reduce to medium.

The three system configurations from A can also be applied here with the similar costs and detection performance assessments as stated above. For option 2, the distance between scanning radars could be increased for congestion detection.

6.5 Secondary road, high traffic volume, no existing detection systems system

6.5.1 Reference System

The infrastructure in this use case is characterised by a Secondary Road (Dual Carriageway). The traffic volume is high. The system has no incident detection available and the infrastructure is currently not prepared to add road side equipment easily, i.e. there are no power supply or cable paths available, nor any poles or gantries.

6.5.2 Requirements

The secondary road network is too extensive to consider expensive road side detection systems as a feasible option. Because the network is extensive, the false alarm rate should be low.

The following requirement sets could be defined by an NRA:

A. Automation of the congestion detection.

B. Automation of the accident, breakdown, AID and congestion detection.

The detection performance required of a new system is:

- Low false alarm rate,
- Medium detection rate,
- High detection time,
- low location accuracy.

6.5.3 Options for incident detection systems

The technology assessment includes 4 options with potentially good prospects (Table 33).The motivations for options 1 – 3 are similar to options 2 – 4 in section 6.2.3 and in section 6.1 respectively. The motivation for option 4 is similar to option 4 in section 6.4.3.

Options 2 and 3 provide an additional possibility for tracking of nomadic devices and cooperative vehicles for the detection of emerging congestion, as an alternative to Automatic Incident Detection (section 5.3.4) in case none equipped vehicles are causing an accident or breakdown.

6.5.4 Assessment of system configurations

The following alternative system configurations can be proposed by combining options that provide cost effective solutions. All options are combined with eCall.

A. Automating congestion detection

1. A service providing traffic data, FCD or travel time data from Nomadic is the most cost efficient solution. The setup costs and maintenance for the NRA are minimal. The congestion detection performance is medium. The detection rate and location accuracy meet the requirements. However, the false alarm rate medium and the detection time may be very high (> 5 minutes).

2. If congestion detection is required with a high detection performance (better than with nomadic devices), then Bluetooth detectors are a cost efficient solution. The false alarm rate is low. The detection time is lower when the BT detectors are positioned at strategic locations on the road within about 5 km distance of each other.

B. Automating accident, breakdown, AID and congestion detection

3. Option 1 can be extended for handling accident and breakdown events from nomadic devices. The detection performance for accidents and breakdowns is estimated as medium and would require verification. There is no system available for verification, so emergency and rescue teams have to be sent out, and the operations costs will be high. .
4. A combination of eCall, Nomadic Devices and Cooperative Systems provides a solution for 2020 and a migration path to reduce the maintenance and operational costs.
    - Till 2020, the Nomadic Devices and the Cooperative Systems provide the detection performance of option 3 and also provide AID. Alternatively, the BT detectors from option 1 can also be used in this phase.
    - When the penetration rate of cooperative vehicles with G5 communication increases, detection performance will increase and meet all requirements.

Table 33: Options for Use Case 4

Option	Technology	Suitability				Costs for a new system		
		Accidents	Break downs	AID	Conges-tion	Setup	Maint.	Oper.
1	eCall					€	€	€
	2020 (PEV = 10%)	Low*)						
	2030	Medium*)						
2	Nomadic Devices					€	€	
	Events	*Medium*	*Medium*					€€€
	RS vehicle tracking of nomadic devices			*Medium*				€€€
	Traffic Data, FCD, Travel time data				*Medium*			€
3	Cooperative systems							
	Configuration 1 (ITS G5)					€€	€€	0
	2020 (PEV = 5%)	*Low*	*Low*	*Medium*	*Medium*			
	2030	Very High	Very High	*Very High*	*Very High*			
	Configuration 2 (3G)	*Low*	*Low*	*Medium*	*Medium*	€	€	0
4	Bluetooth detectors				*High*	€€	€	€

*) Provides only events for major accidents

6.6 Secondary road, low traffic volume, no existing detection systems system

6.6.1 Reference System

The infrastructure in this use case is characterised by a Secondary Road (Dual Carriageway). The traffic volume is low. The system has no incident detection available and the infrastructure is currently not prepared to add road side equipment easily, i.e. there are no power supply or cable paths available, nor any poles or gantries.

6.6.2 Requirements

The requirements for low volume traffic are similar to those for high volume secondary roads in section 6.5.2.

The secondary road network is too extensive to consider expensive road side detection systems as a feasible option. Because the network is extensive, the false alarm rate should be low.

The following requirement sets could be defined by an NRA:

C. Automation of the congestion detection.

D. Automation of the accident, breakdown, AID and congestion detection.

The detection performance required of a new system is:

- Low false alarm rate,
- Medium detection rate,
- High detection time,
- low location accuracy.

6.6.3 Options for incident detection systems

The technology assessment includes 4 options with potentially good prospects (Table 34). The motivations for options 1 – 3 are similar to options 2 – 4 in section 6.2.3 and in section 6.1 respectively. The motivation for option 4 is similar to option 4 in section 6.4.3.

The options are similar to those for Use Case 4 (Table 33). The main differences with the high volume traffic situation, are that in low volume traffic:

- Tracking of nomadic or cooperative vehicles may not work sufficiently due to the lower number of equipped vehicles near incidents. AID functionality is not included in the options.
- Services based on nomadic devices providing traffic data, FCD or travel time data, may require a much larger detection time due to the low number of equipped vehicles.

6.6.4 Assessment of system configurations

The same alternative system configurations can be proposed as for the high volume secondary roads (section 6.5.4).

The performance of nomadic devices-based services (option 2, configurations 1 and 3 below) may not be sufficient, especially the false alarm rate, detection rate and detection time, in low volume secondary roads (see section 5.3.2). This needs to be evaluated in specific Use Cases of an NRA.

Table 34: Options for Use Case 5

Option	Technology	Suitability: Accidents	Suitability: Breakdowns	Suitability: Congestion	Costs for a new system: Setup	Costs for a new system: Maint.	Costs for a new system: Oper.
1	eCall				€	€	€
	2020 (PEV = 10%)	Low*)					
	2030	Medium*)					
2	Nomadic Devices				€	€	
	Events	*Medium*	*Medium*				€€€
	RS vehicle tracking of nomadic devices						€€€
	Traffic Data, FCD, Travel time data			*Medium*			€
3	Cooperative systems						
	Configuration 1 (ITS G5)				€€	€€	0
	2020 (PEV = 5%)	*Low*	*Low*	*Medium***)			
	2030	Very High	Very High	*Very High***)			
	Configuration 2 (3G)	*Low*	*Low*	*Medium***)	€	€	0
4	Bluetooth detectors			*High*	€€	€	€

*) Provides only events for major accidents
**) Congestion detection primarily through event detection like Traffic Jam Ahead Warning

A. Automating congestion detection

1. A service providing traffic data, FCD or travel time data from Nomadic is the most cost efficient solution. The setup costs and maintenance for the NRA are minimal. The congestion detection performance is medium. The detection rate and location accuracy meet the requirements. However, the false alarm rate medium and the detection time may be very high (> 5 minutes).

2. If congestion detection is required with a high detection performance (better than with nomadic devices), then Bluetooth detectors are a cost efficient solution. The false alarm rate is low. The detection time is lower when the BT detectors are positioned at strategic locations on the road within about 5 km distance of each other.

B. Automating accident, breakdown, AID and congestion detection

3. Option 1 can be extended for handling accident and breakdown events from nomadic devices. The detection performance for accidents and breakdowns is estimated as medium and would require verification. There is no system available for verification, so emergency and rescue teams have to be sent out, and the operations costs will be high. .
4. A combination of eCall, Nomadic Devices and Cooperative Systems provides a solution for 2020 and a migration path to reduce the maintenance and operational costs.
   - Till 2020, the Nomadic Devices and the Cooperative Systems provide the detection performance of option 3 and also provide AID. Alternatively, the BT detectors from option 1 can also be used in this phase.

   - When the penetration rate of cooperative vehicles with G5 communication increases, detection performance will increase and meet all requirements.

7 References

[1] A. Adesiyun et al., "User Needs and Requirements for Incident Detection Systems," RAIDER Deliverable D2.1, 2012.

[2] EasyWay, "Deployment Guideline - Traffic Management Services - Incident Warning and Management," TMS-DG05-08, Version 02-00-00, 2012a. [Online]. http://www.easyway-its.eu/download/533/6103

[3] Roberto Nenzi and et al, "The Data Quality Aspect in ITS Framework and Best Practices," 2012. [Online]. http://www.easyway-its.eu/document-center/document/open/#

[4] C Quiroga, K Hamad, and Eun Sug Park, "Incident detection optimization and data quality control," Texas Transportation Institute, Report 0-4745-3 2005.

[5] "European Road Statistics 2008," European Union Road Federation (ERF),.

[6] EasyWay, "Operating Environments - Information and Communication Technologies - Supporting Guidelines," 2012b. [Online]. http://www.easyway-its.eu/download/533/6103

[7] UMTS Forum, "Mobile traffic forecasts 2010-2020 report," 2011. [Online]. http://www.umts-forum.org/component/option,com_docman/task,doc_download/gid,2537/Itemid,213/

[8] Anna Schirokoff, Pirkko Rämä, Niina Sihvola, and Risto Kulmala, "Scenarios for market acceptance and penetration," 2008.

[9] (2010) NXP Automotive Telematics On-board unit Platform (ATOP). [Online]. http://www.nxp.com/documents/leaflet/939775016910.pdf

[10] (2012, October) European vehicle manufacturers working hand in hand on deployement of cooperative Intelligent Transport Systems and Services (C-ITS). [Online]. http://its-standards.info/Feeds/C2C-CC%20201210-Press%20release%20on%20MoU_Version1.0.pdf

[11] Sophia Chirskaya, "Galileo Applications on the European Motorway Network," in *2nd EasyWay Annual Forum*, Vienna, 2009. [Online]. http://www.easyway-its.eu/events/2009-wien/proceedings/

[12] (2013) Satellite navigation - Galileo: Applications for road transport. [Online]. http://ec.europa.eu/enterprise/policies/satnav/galileo/applications/road/index_en.htm

[13] R. Kulmala, "Proposal for ICT infrastructure quality levels," in *2nd EasyWay Annual Forum*, vienna, 2009. [Online]. http://www.easyway-its.eu/events/2009-wien/proceedings/

[14] Daniel Elias, Birgit Nadler, and Andrea Schieferstein, "State of the art analysis - Software and Services for Quality Management of Traffic Data," QUATRA Deliverable D2.1, 2012.

[15] Waze - outsmarting traffic, together. [Online]. www.waze.com

[16] J van Huis and J Baan, "Incident detection using video based monitoring," in *ITS Europe*, Lyon, 2011, p. TS20 / Incident Management.

[17] B Morris and M Trivedi, "VECTOR: trajectory analysis for advanced highway monitoring," in *ITS America Annual Meeting*, 2009, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.160.1055&rep=rep1&type=pdf.

[18] P.T. Martin, J Perrin, and B Hansen, "Incident detection algorithm evaluation," Utah DoT, 2001.

[19] Angshuman Guin, "An incident detection algorithm based on a discrete state propagation model of traffic flow," Georgia Insitute of Technology, PhD thesis 2004.

[20] E Parkany and Chi Xie, "A complete review of incident detection algorithms & their deployment: what works and what doesn't," New England Transportation Consortium, NETCR37, 2005.

[21] "Automatic Incident Detection – TRRL Algorithms HIOCC and PATREG," TRRL Supplementary Report 526,.

[22] Indu Sreedevi. (2005) Incident Detection - Detection Algorithms. [Online]. http://fresno.ts.odu.edu/newitsd/ITS_Serv_Tech/incident_manag/detection_algorithms_summary.html

[23] "Systems Engineering & Assessment Ltd specifications ," SEA/02/TR/3706 and SEA/02/TN/3940,.

[24] Arne Oostveen, Hans Bokma, Daisy Poot-Geers Willem Jan Knibbe, "A New Incident Detection Scheme developed in The Netherlands," in *8th International IEEE Conference on Intelligent Transportation Systems*, Vienna, Austria, 2005, p. 6.

[25] Ioannis Papamichail, "Review of available case studies and related scientific knowledge," Nearctis, Deliverable 7, version 2 2010.

[26] Thomas Durlin, Patrick Palmier, and Alexis Bacelar, "Estimation of automatic incident detection benefits on Lille urban express roads," in *5th EasyWay Annual Forum*, London, 2012. [Online]. http://www.easyway-its.eu/userfiles/AF_2012/proceedings/Estimation_of_automatic_incident_detection_benefits.pdf

[27] Manoel Mendonca de Castro-Neto, "Towards Universality in Automatic Freeway Incident Detection: A Calibration-Free Algorithm," University of Tenessee, 2009.

[28] Susanne Breitenberger, "Necessary penetration rates of probe vehicles," in *ITS*, 2010. [Online]. http://www.bmwgroup.com/e/0_0_www_bmwgroup_com/forschung_entwicklung/mobilitaet_verkehr/verkehrsforschung/ExtendedFloatingCarData_e1.pdf

[29] B.S. Kerner et al., "Traffic State Detection with floating Car Data in Road Networks," in *8th International IEEE Conference on Intelligent Transportation Systems*, Vienna, 2005.

[30] Philippe Thomin, Alain Gibaud, and Pierre Koutcherawy, "Deployment of a fully distributed system for improving urban traffic flows: A simulation-based performance analysis," *Simulation Modelling Practice and Theory*, vol. 31, pp. 22-38, 2013.

[31] Jozef Cannearts and Mario Vanlommel, "Floating Car Data for Network Traffic Management," in *5th EasyWay Annual Forum*, London, 2012. [Online]. http://www.easyway-its.eu/userfiles/AF_2012/proceedings/Floating_Car_Data_for_Network_Traffic_Management.pdf

[32] Raza Muhammed, "Travel time estimation based on Bluetooth sensors," in *5th EasyWay Annual Forum*, London, 2012. [Online]. http://www.easyway-its.eu/userfiles/AF_2012/proceedings/Travel_Time_Estimation_based_on_Bluetooth_Sensors.pdf

[33] Functions of DRIVE-C2X. [Online]. http://www.drive-c2x.eu/use-cases

[34] Martin Schönhof, Martin Treiber, Arne Kesting, and Dirk Helbing, "Autonomous detection and anticipation of jam fronts from messages propagated by intervehicle communication," *Journal of the Transportation Research Board*, vol. 1999, pp. 3-12, 2007.

[35] R. Bauza, J. Gozalvez, and J. Sanchez-Soriano, "Road traffic congestion detection through cooperative vehicle-to-vehicle communications," in *IEEE LCN Workshop on User Mobility and Vehicular Networks*, Denver (USA), 2010.

[36] H. Rohling and H. Busche, "SOTIS: a Self-Organizing Traffic Information System based on Car-2-Car Communications," *IEEE Transactions on ITS*, 2005.

[37] Mobilitäts Daten Marktplatz. [Online]. www.mdm-portal.de

[38] Bart Netten et al., "Improving moving jam detection performance with V2I communication," in *ITS World Congress*, Tokyo, 2013.

[39] eCall: Time saved = lives saved. [Online]. http://ec.europa.eu/information_society/activities/esafety/ecall/index_en.htm

[40] HeERO - Harmonised eCall European Pilot. [Online]. http://www.heero-pilot.eu/view/en/home.html

[41] "Intelligent Transport Systems (ITS);Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service," ETSI TS 102 637-2 V1.2.1 (2011-03),.

[42] DRIVE C2X - Connecting vehicles for safe, comfortable and green driving on European roads. [Online]. http://www.drive-c2x.eu/

[43] FOTsis - European Field Operational Test on Safe, Intelligent and Sustainable Road operation. [Online]. http://www.fotsis.com/

[44] I. Passchier et.al., "Influencing driving behavior via in-car speed advice in a field operational test," in *9th ITS European Congress*, Dublin, 2013.

[45] I. Passchier et al., "Influencing driver behavior via in-car speed advice in a field operational test," in *ITS Europe*, Dublin, 2013.

[46] L. Morris et al., "Investigation of millimetric radar and an inductive loop based classification system, as a method of incident detection on live carriageways Phase 2 Report," TRL, CPR391,.

[47] "UK's Hindhead tunnel pushes the boundaries of traffic management," *ITS International*, http://www.itsinternational.com/categories/detection-monitoring-machine-vision/features/uks-hindhead-tunnel-pushes-the-boundaries-of-traffic-management/?locale=en.

[48] "Directive 2004/52/EC of the European Parliament and the Council of 29 April 2004 on the interoperability of electronic road toll systems in the Community,".

[49] B Heilmann et al., "Predicting Motorway Traffic Performance by Data Fusion of Local Sensor Data and Electronic Toll Collection Data," *Computer-Aided Civil and Infrastructure Engineering*, vol. 26, no. 6, pp. 451-463, August 2011.

[50] Angelo Rossini, "From tolling system to travel time and user information applications," in *2nd EasyWay Annual Forum*, Vienna, 2009. [Online]. http://www.easyway-its.eu/events/2009-wien/proceedings/

[51] Connekt, "ITS in the Netherlands," Ministry of Infrastructure and the Environment, 2011.

[52] RAIDER. (2012) Specialist consultation Questionnaire. [Online]. http://www.fehrl.org/index.php?m=324

[53] CEDR Task Group 05, "Traffic Incident Management," 2009.

[54] *Traffic Incident Management Handbook - Florida APTS program*.: PB Farradyne, 2000, floridaapts.lctr.org/pdf/incident%20mgmt_handbook%20Nov00.pdf.

[55] Nicholas Owens and et.al., *Traffic Incident Management Handbook*.: USDOT - FHWA, 2010, vol. FHWA-HOP-10-013, http://ops.fhwa.dot.gov/eto_tim_pse/publications/timhandbook/tim_handbook.pdf.

[56] M. Strauss and U. Staehlin, "Safety Margin concept," SAFESPOT Deliverable D4.2.2, 2007.

[57] eCall Driving Group, "Recommendations of the DG eCalll for the introduction of the pan-European eCall," eSafety Forum, 2006.

[58] "Vision Zero,".

[59] R Benedik, "Applied incident management for selective prevention and release in safety critical situations," in *ITS Europe*, Lyon, 2011, p. TS 20 / Incident Management.

[60] S Collins, "Improving road safety via incident management: implementing a video image processing system," in *ITS Europe*, Lyon, 2011, p. TS20 / Incident management.

[61] S Vandebuerie, "Video-based highway monitoring," in *ITS Europe*, Lyon, 2011, p. TS20 / Incident management.

[62] A MacCarley, "City of Anaheim/Caltrans/FHWA advanced traffic control system field operational test evaluation: task C Video traffic detection system," California PATH Research Report UCB-ITS-PRR-98-32, 1998.

[63] "Evaluation of an image detection system for hard shoulder monitoring - on road trial report," 2006.

[64] *Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on minimum safety requirements for tunnels in the trans-European road network*., vol. Official Journal of the European Union 1. 167 of 30 April 2004.

[65] MediaTunnel. [Online]. http://www.citilog.com/products/mediatunnel.html

[66] A Wijbenga, J Bac, and S Boerma, "Een nieuwe manier van verkeerswaarneming? Bluetooth (in Dutch)," in *Nationaal Verkeerskundecongres*, Rotterdam, 2010, http://www.verkeerskunde.nl/Uploads/2010/10/B50-Een-nieuwe-manier-van-verkeerswaarneming-Bluetoothx.pdf.

[67] C.A. MacCarley, "Evaluation of commercial video-based intersection signal actuation systems; final project progress report," Caltrans, Document No. CP-VIDE-FR-01, 2008.

[68] CARE (EU road accidents database) or national publications. [Online]. http://ec.europa.eu/transport/road_safety/pdf/observatory/historical_evol.pdf

[69] Paul Riley, "Evaluation of telematic application pilot imlemented on highway D8 in Czech Republic," in *2nd EasyWay Annual Forum*, Vienna, 2009. [Online]. http://www.easyway-its.eu/events/2009-wien/proceedings/

[70] Thomas Scheider, Doug Newton, Risto Öörni, and Astrid Kellermann, "Report on service benefits and costs," Deliverable 2 2010. [Online]. http://www.quantis-project.eu/QUANTIS_D2_final_incl_annexes.pdf

[71] The fast-growing role of in-car systems in Traffic Management. [Online]. http://www.tomtom.com/en_gb/licensing/downloads/download-WTM.jsp?WT.ac_id=ttlic_download_WTM

[72] Francsics Jonathan and et.al., "Impact assessment on the introduction of the eCall service in all new type-approaved vehicles in Europe, including liability / legal issues," European Commission, Final Report Issue 2 SMART 2008/55, 2009.

[73] "Commission staff working paper impact assessment on the support of an EU-wide eCall service in electronic communication networks for the transmission of in-vehicle emergency calls based on 112 ('eCalls')," European Commission, 2011. [Online]. http://ec.europa.eu/information_society/activities/esafety/doc/ecall/recomm/imp_assessm_fin.pdf

[74] Isabel Wilmink and et.al., "Impact Assessment of Intelligent Vehicle Safety Systems," 2008.

[75] EasyWay, "The Data Quality Aspect in ITS Framework and Best Practices," 2012. [Online]. http://www.easyway-its.eu/document-center/document/open/#

Annex 1 Technology Library

This is a library of fact sheets for innovative technologies that have been considered to improve for incident detection. The fact sheets give a brief description of the technology and characterises the performance of costs for configuration for each of the incident detection systems. The assessments from all technologies are summarized in the following table.

Table 35: Overview of the assessments of detection performance and costs

Technology	*Accidents & Breakdowns*					
	DR	DT	FAR	LA	Vehicle Class & Dangerous Goods	Suitability
Minimum Requirement (section 2.4)	High	Medium	High	Very High	Both	
eCall	Low	Medium	Low	High	Both	Low
Cooperative Systems configuration 1 (ITS G5 + RIS)	Low	Low	Low	Very High	Both	Low
Cooperative Systems configuration 2 (3G)	Low	Medium	Low	Very High	Both	Low
Nomadic Devices	Medium	High	High	High	No	Medium
Scanning Radar	High	Low	High	Very High	No	High
Video Tracking	High	Low	High	Very High	Both*	High

* Vehicle class, Dangerous goods by manual inspection of video

eCall	Medium	Medium	Low	High	Both	High
Cooperative Systems configuration 1 (ITS G5 + RIS)	High	Low	Low	Very High	Both	Very High

Annex 1.1 eCall

eCall [39] is an in-vehicle emergency system that automatically calls the Public Safety Answering Point (PSAP) and sends the most relevant accident information to initiate emergency response. The call is made automatically when a severe crash is detected by in-vehicle system like an airbag activation. Alternatively passengers can activate the system manually, for example in case of a heart attack or to report an accident witnessed. The main objective of eCall is to reduce the time to respond for emergency services via an alarm centre, not as an incident detection system for road authorities or traffic control centres.

Immediately upon detection of an accident or passenger activation the eCall system automatically sends the minimum set of data to the PSAP, including time and location of the accident and basic vehicle information, and it opens a 112 call to the PSAP. The PSAP may be a 112 alarm centre or an intermediate service provider that forwards the call to the local 112 alarm centre. The voice communication enables the alarm centre operator to acquire more information from the passengers.

eCall systems can be provided with a new vehicle by 3.2.2the manufacturer or as an aftermarket system by third parties. eCall by default makes use of the free 112 service that has to be provided by mobile network operators throughout Europe. It cannot be assumed that every vehicle has a subscription with a service provider and may not be capable to initiate other connections to services or a traffic centre, nor to provide additional information for incident detection.

The current status of development is that eCall standards are being defined by ETSI, and field trials are held in the HeERO [40] project in several locations throughout Europe. First eCall products are expected on the EU market by 2015 in passenger cars and light duty vehicles. An estimate for penetration rates PEV_{eCall} by 2020 and 2030 are made in section 3.2.2.

The in-vehicle systems that trigger the automatic emergency call, such as the airbags and collision sensors are a reliable detection system for vehicle crashes. These sensors will not trigger on minor accidents though (section 2.4). It can be assumed though that the 112 call cannot be used to report material damage, broken down vehicles or congestion. This implies that the minor accidents cannot be reported manually by occupants via eCall.

From the 25% of major accidents (F_{major}), those accidents involving an eCall equipped vehicle will be detect automatically. It is difficult to estimate the percentage of other major accidents that will be reported manually via eCall ($MDIR_{eCall}$): let's assume this is 10% (Table 36).

Here, it is assumed that the detection rate is the sum of automatic detections of eCall equipped vehicles having an accident with any type of other vehicle (PEV_{eCall} of all major accidents) and manually generated events ($MDIR_{eCall}$) of nearby accidents ($1 – PEV_{eCall}$).

eCall performance estimates are summarized in Table 36. The detection rate, false alarm rate and location accuracy of automatically generated events will be similar to accident events generated by cooperative systems (Table 39). Manually generated events will be similar to the nomadic devices (Table 45).

Table 36: Guestimates for accident detection performance of eCall services

Performance criterion		*Estimate / Equation*
$MDIR_{eCall}$	Manual driver intervention rate for using eCall, in case the host vehicle is not involved in an major accident directly but witnesses and accident	*10%*
DR_{eCall}	Detection Rate of major accidents by eCall services; i.e. percentage of automatic accident detections and users manually reporting nearby accidents:	$PEV_{eCall} + MDIR_{eCall} * (1 - PEV_{eCall})$
DT_{eCall}	Detection Time of major accidents including road user reaction time and communication via service provider	*> 1 min*
FAR_{eCall}	False Alarm Rate of manual eCall accident reporting	$5\% * (IR_A * F_{major}) * DR_{eCall}$
LA_{eCall}	Accuracy of accident location	*+/- 5 m*
VC	Vehicle classification	*Yes*
DG	Dangerous goods	*No*

The event generated by an eCall system could also serve as an accident detection to alarm the traffic operator, and potentially as a means to verify the accident and collect additional information via voice communication. However, this is not formally supported by the eCall standards and mandate. The eCall system has to be extended for road operators for accident detection:

1. The PSAP or alarm centre has to forward the accident information without delay, to enable the road operator to respond immediately, and provided added value to existing detection systems.
2. The information needed by the road operator has to be collected by the PSAP or alarm centre, such as the number of vehicles involved in the crash, and the lanes that are blocked.

In this report, it is assumed that these two extensions will be realized by 2020, either by eCall or by the systems that include eCall.

Annex 1.1.1 Accidents

Detection Performance

Detection performance is primarily determined by the penetration rate of equipped vehicles. The in-vehicle systems, such as the airbags and collision sensors are a reliable detection system for vehicle crashes. These sensors will not trigger on minor accidents though. It is difficult to predict the percentage of minor accidents that will be called in manually, or the percentage of false alarms. It can be assumed though that the 112 call cannot be used to report material damage, broken down vehicles or congestion. Performance is estimated from Table 36.

Detection Rate

Detection rate depends primarily on the penetration rate of equipped vehicles, and the percentage of manual calls to report an accident of other vehicles. The detection rate for major accidents is $DR_{eCall} = DR_{eCall} = 19\ \%$

The detection rate is further reduced to major accidents. The detection rate for accidents in general is $DR_A = DR_{eCall} * F_{major} = 5\%$

Detection Delay

Automatic detection of an accident by vehicle systems is within a sec after a crash. Communication to the PSAP and forwarding to the traffic control centre of the initial call will possible within seconds.

A manual eCall will have a delay comparable to drivers calling an emergency via their mobile phones. Delay between the accident and the call may vary and will be in the order of minutes $DT_A = DT_{eCall} > 1$ min.

Detection Accuracy

The location of the incident and vehicle information are generated by in-vehicle systems and expected to be very accurate $LA_A = LA_{eCall} = +/- 5$ m

False Alarm Rate

The false alarm rate is mainly determined by the number of false manual calls. It can be assumed that such false calls are filtered by the PSAP or alarm centre during the voice call, and that the initial eCall to the traffic centre will be revoked:

$FAR_A = FAR_{eCall}$

= 0.016 [false alarms / year / km] on motorways

= 0.006 [false alarms / year / km] on secondary roads

Setup considerations and costs

For a new system, or for retrofitting and existing system, the only setup cost for the road authority is the interface to the PSAP or alarm centre to receive eCalls.

Operations - considerations and costs

It is assumed that the validation of the call is handled by the PSAP or alarm centre. No costs involved for the road authority.

Annex 1.1.2 Assessment

Table 37: Performance for eCall service

	Accidents			Breakdowns and Congestion
	minor	major (2020)	major (2030)	
System Configuration	N/A	PEV_{eCall} = 10%	PEV_{eCall} = 90%	N/A
Detection Rate		Low	Medium	
Detection Time		Medium (< 1 min for automatic > 1 min for manual)	Medium	
Location Accuracy		Medium (+/- 5 m)		
Vehicle class & Dangerous goods		From voice communication		
False Alarm Rate		Low		
Suitability	N/A	Low	Medium	
	Low			

Table 38: Costs for eCall service

	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€ (only for interface to PSAP or alarm centre to receive the eCalls).		N/A
Maintenance	€		
Operations	€ (False alarms from manual eCalls will be filtered primarily by PSAP or alarm centre)		

Annex 1.2 Cooperative Systems

A cooperative ITS is an intelligent transportation system in which vehicles, road infrastructure and back offices cooperate to improve active road safety and traffic efficiency. The cooperative vehicles and road side units have an ITS Station with a standardised architecture including a communication unit and an application unit. An ITS Station runs applications that cooperate with other ITS stations via short range ITSs G5 (802.11p) communication or via a mobile cellular network communication (3G – 4G).

The architecture, communication and applications are being standardised by ETSI, CEN and ISO. A first Basic Set of Applications [41] is being defined that include applications relevant to each incident class considered, such as a post-crash warning, collision warning, stationary vehicle warning, and traffic jam ahead warning. Although the systems, applications and standards are still in development, it is likely that cooperative systems will be available with detection for accidents, broken down vehicles and congestion.

A cooperative system has an ITS Station, which is a platform to run the cooperative applications and provides communication with other ITS Stations via ITS G5 geonetworking or via 3G cellular networks. In the future, new technologies like LTE will also be integrated. A Vehicle ITS Station (VIS) integrates with the on-board network and sensor, for example to detect a collision or a malfunction. This implies that the detection of an accident or vehicle breakdown of the host vehicle can be assumed to be very reliable, accurate and fast.

A VIS is directly connected to in-vehicle sensors and systems, and uniquely identifies the vehicle. This distinguishes cooperative systems from nomadic devices; i.e. nomadic devices may be installed in a vehicle, without having access to the in-vehicle sensors and systems, or the nomadic device is held by an occupant that temporarily resides in the vehicle, can be used in different vehicles and outside the vehicle.

System Configuration

There are two configurations to communicate the on-board detections to road operators:

1. The road authority has its own network of road side units deployed along the road that can receive the messages from equipped vehicles via the ITS G5 communication network and send the information directly to the traffic control centre for operator support within a second. This system configuration is developed and field tested in the DRIVE C2X project for example [42].
2. A service provider collects the vehicle information via a cellular network and processes the data in a back office. This system configuration is developed and field tested in the FOTsis project for example [43].
    - If the road authority provides the service, then the information can be provided directly to the road operator. The end-to-end communication delay can be as low as 10 seconds [44].
    - If the road authority has to acquire the data from the third party service provider, then the end-to-end delay may be in the order of 5 minutes

The first option requires road side units. To receive accident or breakdown warnings from the vehicles, or to track vehicles, full ITS G5 communication coverage is required. With a typical communication range of 500m, a RIS is needed every 1 km:

$$DENS_{RIS} = 1.0 \text{ RIS per km of road}$$

The penetration rate of VIS and RIS (in case of option 1) determines the performance of cooperative systems. European vehicle manufacturers intend to bring the first cooperative systems to the market in 2015 [10]. There is no mandate, however, like for eCall, so an estimate of the penetration rate at 2020 is difficult to make. It is likely though that VIS will be combined with eCall systems by car manufacturers. In [8] a penetration rate was estimated for incident related cooperative applications between 5-10% by 2020 when introduction would be initiated by 2012. By 2030 most vehicles are expected to be equipped with ITS Stations, possibly integrated with eCall. A first guestimate for a penetration rate is:

$$PEV_{V2I} = 5\% \text{ by } 2020$$

$$PEV_{V2I} = 90\% \text{ by } 2030$$

As with eCall this penetration rate is likely to increase strongly by 2030 because of the inherent safety features for car manufacturers.

Road authorities are starting up initiatives to develop a road side infrastructure at specific locations and TERN corridors. The required RIS densities will be estimated for the incident classes below.

Detection Accuracy

A VIS uses a GNSS component in the vehicle for absolute positioning, similar to a nomadic device. The on-board positioning is commonly based on standard GPS systems with a typical location accuracy of +/- 10 m or less. It can be expected that the positioning improves by 2020 to also provide lane level accuracy of +/- 1 m (section 3.2.4).

In addition, the VIS makes use of on-board motion state sensors and systems for INS to improve positioning accuracy. The in-vehicle systems accurately determine their position, speed, acceleration, yaw rate and heading with frequencies of 1 Hz or higher.

Cooperative systems are broadcasting vehicle information, including the vehicle type and class, acceleration and speed, driving direction, and possibly whether dangerous goods are transported. Vehicles do not have on-board sensors and diagnostics to detect vehicle fires.

Detection Time

The on-board detection of incidents is instantly within 1 sec. The time delay in receiving vehicle data is determined by the communication media and the communication frequency for the two configuration options:

1. When ITS G5 communication is used between a VIS and a RIS, then the communication frequency is 1 - 10 Hz and the detection delay is < 1 sec.
2. When 3G cellular communication is used to send vehicle data via a service provider to a road operator, then the minimum communication delay is 10 sec [45] for sending incident warnings or floating car data. The update frequency of floating car data can be in the order of 1 min for vehicle tracking.

Detection Rate

The cooperative applications will be standardized and presumably certified in some way. The applications use on-board sensors and systems with a high reliability. It can be assumed that the detection rate of incidents is near 100% on all equipped vehicles. The detection rate overall is proportional to the penetration rate of equipped vehicles.

Setup considerations and costs for a new system

In the first system configuration option, the road authority has to install new Road Side Units (RSU). A road side unit contains a communication unit and an application unit with application software. A road side unit costs 3000 – 4000 €. This hardware can either be mounted on a pole or gantry on the side, above the road. The RSU needs to be connected directly or via Wi-Fi to the fixed IP network of the road authority.

Setup considerations and costs for retrofitting existing infrastructure
If the infrastructure already exist with a fixed communication network and detection systems (e.g. inductive loops), then retrofitting only requires the installation of the RIS.

Maintenance considerations and costs
No maintenance is to be expected other than normal upgrades of the hardware and software of RSUs.

Operations considerations and costs
The messages from V2I communication contain most relevant data about incidents. No operational efforts or costs are required to verify the incidents received from cooperative systems.

Annex 1.2.1 Accidents and Breakdowns

The Basic Set of Applications contains several cooperative applications for the detection of accidents and vehicle breakdowns, such as post-crash warning, collision warning, obstacle warning, emergency electronic brake light warning, stationary vehicle warning, and car breakdown warning. Detection performance is estimated in Table 39.

Table 39: Guestimates for in-vehicle (VIS) accident and breakdown detection performance

Performance criterion for accident or breakdown detection		*Estimate*
$DENS_{RIS}$	Density of RIS	1 RIS/km
DR_A, DR_B	Detection Rate	$\approx PEV_{V2I}$
DT_A, DT_B	Detection Time with G5 V2I communication to a RIS (configuration option 1)	*< 1 sec*
DT_A, DT_B	Detection Time with cellular network communication to a service provider (configuration option 2)	*10 sec*
FAR_A	False Alarm Rate for accidents	$<< 1\ \% * IR_A * DR_A$
FAR_B	False Alarm Rate for breakdowns	$<< 1\ \% * IR_B * DR_B$
LA_A, LA_B	Location accuracy of on-board positioning	*< +/- 1.0 m*
VC	Vehicle class	*Yes*
DG	Dangerous goods	*Yes*

These applications detect accidents and breakdowns automatically from on-board sensors and systems. The false alarm rate is expected to be negligible.

FAR_A = 0.003 [false alarms / year / km] on motorways
0.001 [false alarms / year / km] on secondary roads

FAR_B = 0.007 [false alarms / year / km] on motorways
0.003 [false alarms / year / km] on secondary roads

Annex 1.2.2 Extraordinary Congestion

The Traffic Jam Ahead Warning (TJAW) is a basic application in which vehicles detect a traffic jam. This application is less reliable, accurate and timely than on-board accident or breakdown detection, because the vehicles do not have sufficient information about the local traffic state with low penetration rates. Nevertheless, cooperation schemes are being developed for distributed decision making to quickly and efficiently determine congestion states and the location of jams in low penetration scenarios, e.g. [30], [34], [35], [36]. Typical algorithms generate a congestion event only when a vehicle is driving at a low speed for a prolonged period of time or distance (e.g. 500 m), and when multiple (e.g. 4) vehicles detect this situation. It will take several minutes before a TJAW warning can be generated, during which the location of the jam has changed as well.

Congestion can also be detected by tracking the equipped vehicles that are broadcasting Cooperative Awareness Messages (CAM) with 1 – 10 Hz. The CAM contains the vehicle information such as position, speed, acceleration, heading, and vehicle class. Warnings from other applications, such a Slow Vehicle Warnings and Emergency Electronic Brake Lights can also be used in addition to the CAM data to determine the jam locations. Alternatively, the floating car data can also be sent to the road operator via mobile cellular network communication (system configuration option 2).

Due to the accuracy of vehicle tracking, the location of congestion can be determined with the accuracy at which traffic jam tails and congestion can be determined. Due to the relatively low penetration rate, false alarms are likely to occur occasionally.

Guestimates for the performance of on-board incident detection systems used in this report is given in Table 40.

Table 40: Guestimates for vehicle tracking on a RIS

Performance criterion		*Estimate*
$DENS_{RST}$	Density of RIS for vehicle tracking	1.0 RIS/km
DR_{RST}	Detection Rate of in-vehicle tracking	$\approx PEV_{V2I}$
DT_{RST}	Detection Time for vehicle positions with G5 V2I communication to a RIS (configuration option 1)	*< 1 sec*
DT_{RST}	Detection Time for vehicle positions or track updates with cellular network communication to a service provider (config. option 2)	*> 10 sec*
DF_{RST}	Detection frequency (CAM broadcast frequency - config. option 1)	10 Hz
	Detection frequency (config. option 2)	< 0.1 Hz
LA_{RST}	Location accuracy of in-vehicle positioning and tracking	+/- 1.0 m

Annex 1.2.3 Assessment – Configuration 1 with G5

Table 41: Performance of Cooperative Systems

<table>
<tr><th rowspan="2"></th><th rowspan="2">Accidents</th><th rowspan="2">Breakdowns</th><th colspan="2">Congestion</th></tr>
<tr><th>TJAW</th><th>tracking</th></tr>
<tr><td rowspan="2">System Configuration</td><td colspan="4">PEV_{V2I} = 5% by 2020 (90% by 2030)</td></tr>
<tr><td colspan="4">Configuration option 1:
DENS_{RIS} = 1.0 RIS / km
ITS G5 (802.11p) short range communication</td></tr>
<tr><td rowspan="2">Detection Rate</td><td colspan="2">Low due to low PEV_{V2I}</td><td colspan="2">High (2020)</td></tr>
<tr><td colspan="2">(High by 2030)</td><td colspan="2">Very High (2030)</td></tr>
<tr><td rowspan="2">Detection Time</td><td colspan="2" rowspan="2">Low
< 1 sec</td><td>High (2020)</td><td rowspan="2">Medium</td></tr>
<tr><td>Medium (2030)</td></tr>
<tr><td>Location Accuracy</td><td colspan="2">High (+/- 1.0 m)</td><td>Medium</td><td>Medium</td></tr>
<tr><td>Vehicle class & Dangerous goods</td><td colspan="4">Yes</td></tr>
<tr><td rowspan="2">False Alarm Rate</td><td colspan="2" rowspan="2">Low</td><td>Medium (2020)</td><td rowspan="2">Medium</td></tr>
<tr><td>Low (2030)</td></tr>
<tr><td rowspan="2">Suitability</td><td colspan="2">Low (2020)</td><td>Medium (2020)</td><td rowspan="2">High</td></tr>
<tr><td colspan="2">Very High (2030)</td><td>Very High (2030)</td></tr>
</table>

Table 42: Costs for Cooperative Systems for system configuration 1 (RIS, G5)

<table>
<tr><th></th><th>New System</th><th>Retrofit to existing infrastructure</th><th>Use/upgrade of existing system</th></tr>
<tr><td>Set Up</td><td>€€</td><td>€</td><td rowspan="3">N/A</td></tr>
<tr><td>Maintenance</td><td colspan="2">€€
(regular maintenance of RIS HW or SW)</td></tr>
<tr><td>Operations</td><td colspan="2">None</td></tr>
</table>

Annex 1.2.4 Assessment – Configuration 2 with 3-4G

Table 43: Performance of Cooperative Systems for system configuration 2 (3-4G)

	Accidents	Breakdowns	Congestion - Tracking
System Configuration	PEV_{V2I} = 5% by 2020 (90% by 2030)		
	Configuration option 2: 3, 3.5, or 4G cellular network communications		
Detection Rate	Low due to low PEV_{V2I}		High
	(High by 2030)		Very High (2030)
Detection Time	Medium > 10 sec		Medium
Location Accuracy	High (+/- 1.0 m)		Medium
Vehicle class & Dangerous goods	Yes		
False Alarm Rate	Low		Medium
Suitability	Low (2020)		High
	Very High (2030)		

Table 44: Costs for Cooperative Systems for system configuration 2 (3-4G)

	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€ (service provisioning with delay of 10 sec)		N/A
Maintenance	€ (regular maintenance of service provider HW or SW)		
Operations	None		

Annex 1.3 Nomadic Devices

In the context of this project and incident detection, devices are considered as nomadic if they are mobile and not integrated with systems and sensors in vehicles. Examples of nomadic devices are navigation systems, Bluetooth devices, mobile phones, smartphones, and fleet management tracking systems.

System Configuration

Although not currently used as a mechanism for incident detection, there is an increasing pool of nomadic devices that could be harnessed as a mechanism for incident detection. Smartphones and other handheld devices can provide a suitable mechanism for direct detection of incidents as well as inferred information about network conditions:

- Direct detection – incidents are detected automatically by a device in the vehicle and an alarm raised
- Indirect detection – vehicles carrying a device perform as probe vehicles to capture data relating to network conditions (speed at certain locations, journey time, vehicle tracking etc.) thus building a real-time dynamic network model of traffic conditions

The following considerations and potential limitations are key to the suitability of these devices:

- Market penetration – in order to replicate the data collected by a traditional data classifier (that is required to predict the onset of congestion such as traffic flow, occupancy), a substantial proportion of vehicles must carry a device to ensure a significant network of probe vehicles exist and network conditions can be predicted with the desired level of confidence. Additionally, incidents detected directly will be limited to incidents involving a vehicle carrying a device.
- Nomadic devices communicate via cellular networks, which are known to have poor coverage in remote areas. In these areas, incident applications will not work obviously.
- Data fusion – there are numerous types of technologies and suppliers of systems. As indicated above, a successful system will require substantial proportion of vehicles to act as probe vehicles. Therefore, data fusion of outputs from disparate technologies/suppliers would be of key importance.
- Data protection issues – there are substantial statutory/legislative restrictions to the collection, handling and use of such data that require consideration.

Nomadic devices should also be differentiated by their communication technology and especially the communication range. Many Bluetooth devices have no GPS, and consequently cannot communicate their position. Instead, Bluetooth detectors are required at the road side to detect and identify passing devices. Traffic data like travel times and congestion can then be inferred from multiple scanning devices along a route, similar to how ANPR and tolling systems can be used. These will be considered in Annex 1.7 in more detail.

Nomadic devices with long range communication, typically 2/3G cellular devices, can be divided by the presence or absence of positioning, typically GPS. Here the focus is on devices with GNNS receivers only, as these can send direct information about their position and speed from any location and time. In contrast to the Bluetooth detectors, these provide a much higher temporal and spatial resolution of traffic data to feed incident detection systems. Examples of algorithms to detect congestion and to fuse probe data with point-based traffic detector data can be found in [12].

Nomadic devices in cars are likely to have a very high penetration rate. For example, according to Ofcom, it is estimated that 58% of people in the UK own a smartphone. However, for incident detection purposes such devices must be ‘enabled’, for example by installing and using a certain app. This reduces the actual penetration of equipped vehicles.

Dedicated navigation devices from service providers have a typical penetration rate below 5%, while the penetration rate of Bluetooth devices is 10-15% in 2011 [31]. Obviously this penetration rate may vary significantly per service provider and country. A penetration rate of 2-3% is found to provide similar detection accuracy of congestion as with ANPR.

We assume that road users with nomadic devices use services and that the NRA or Traffic Control Centre acquire the data through service providers. The NRA may act as a service provider, or acquire the data from third party service providers. The effective penetration rate of nomadic devices PEV_{ND} and detection performance may significantly vary for the specific services provided.

Detection Accuracy

The accuracy of vehicle positioning is determined by the quality of the GNSS sensor in the device. By 2020, it is expected that this accuracy is slightly lower than for eCall devices: $LA_{ND} = LA_{eCall} = +/- 8$ m. This is due to the fact that nomadic devices such as smartphones are often carried in a pocket or are mounted in a way that the GNSS antenna is shielded. In contrast to that, the antenna of eCall systems is supposed to be mounted on a fixed place with sufficient coverage. It must also be noted that GNSS receivers built in a smartphone have varying quality depending on the device model.

However, there are still the problems of low satellite coverage in urban or mountainous areas, multipath effects or low startup performance (also called time to first fix). A method to enhance the performance of standard in-built GPS is Assisted GPS (A-GPS), which uses information about satellite locations via the cellular network and/or WiFi networks. By 2020, the number of available GNSS is expected to be increased, because GALILEO, GLONASS and other GNSS can be utilized.

Setup considerations and costs for a new system

There are two ways of setting up a new system based on nomadic devices: firstly, existing devices are utilized by installing an app. Secondly, a specific user group (e.g. a fleet) is provided with devices. In both cases there are relatively minor costs.

Maintenance of nomadic devices mainly affects software (app) updates rather than hardware replacements. Each smartphone user is responsible for the proper functionality of his/her device. However, even smartphone replacements/repairs cause low costs and hence overall maintenance costs are considered very low.

As long as the nomadic device is online and the app is active, the system can perform automatically. However, an operator may be needed to validate detected incidents and minimize false alarms. Nomadic devices or service providers do not provide any means for validation of incidents, and given that the FAR can be high, a considerable operational cost may be involved for validation of accidents or breakdowns. No validation is assumed to be required for congestion incidents. The costs for client-server communication and data storage and computation are considered low.

Setup considerations and costs for retrofitting an existing infrastructure

If the client-server infrastructure was already set up, the retrofit costs only affect minor hardware or software adaptations.

Maintenance and operational costs would be low, as for a new system.

Use/upgrade of existing system
If the client-server infrastructure was already set up, the upgrade costs only affect minor hardware or software adaptations.

Maintenance and operational costs would be low, as for a new system.

Annex 1.3.1 Accidents

Accidents can be directly detected by nomadic devices in two ways:

1. Automatic - An application on the device can infer the occurrence of an accident from its accelerometers, under the assumption that the device is securely mounted to the vehicle. To avoid too many false alarms, it is expected that a detected accident is only reported after manual confirmation.
2. Manual - An application on the device can allow the user to report the occurrence of an accident manually through some emergency or rescue service, as for example in Waze [15].

Guestimates for the performance specifications are collected in Table 45 and motivated below.

Table 45: Guestimates for manual and automatic accident detection performance on Nomadic Devices by 2020

Performance criterion for accident detection		*Estimate*
PEV_{NDA}	Penetration rate of vehicles equipped with a nomadic device with an accident application	25%
DR_A	Detection Rate of accidents	70%
DT_A	Detection Time with cellular network communication via a service provider with priority	< 2 min
FAR_A	False Alarm Rate for accidents	$5\% * IR_A * DR_{NDA}$
LA_A	Location accuracy of on-board positioning	LA_{ND}

Penetration Rate

Currently, there are several applications on the market, each with a small market share. It can be expected that the market will concentrate more when these apps become successful, for example by third party service providers covering the gap of eCall for minor accidents. Therefore we assume a penetration rate of 25% by 2020.

Detection Time
Nomadic devices with accelerometers, such as smartphones, are potentially able to detect accidents immediately, but the confirmation and validation by the user cause additional delays. It is likely that data must be obtained through third party service providers, which will increase transmission and processing time. It can also be expected that service providers will provide the event reports with priority. The maximum delay is set to 2 minutes.

Detection Rate
The detection rate is defined as the ratio of accidents detected automatically or manually. Automatic detection of accidents depends on the penetration of equipped vehicles. Assuming

that eventually a manual event will be generated by one or more of the passing equipped vehicles, the detection ratio can be higher.

False Alarm Rate

Although accelerometers can detect major decelerations due to major accidents, they may not be sensitive enough and lack the contextual information to detect minor incidents. False alarms can also be caused by heavy emergency brakes or other strong kinematic phenomena to avoid the accident. Therefore there is a relatively high possibility of false alarms. The indicators for classifying an accident must be chosen wisely and an operator could be used to validate the detection. The FAR can be expected to be higher than for manual eCall events, say 5% of all reported accidents are false alarms:

FAR_A = 0.44 [false alarms / year / km] on motorways

0.18 [false alarms / year / km] on secondary roads

Annex 1.3.2 Breakdowns

Breakdowns cannot be detected automatically by nomadic devices because they have no interface to the in-vehicle systems. Many applications exist to manually report a stranded vehicles as information to other road users (e.g. Waze [15]) or to report a breakdown and to request rescue services. These service providers may not forward this information to road operators though for incident detection. This information could also be provided as a service to road operators. Road operators have several alternatives to acquire this information and to increase the penetration and detection rate of cooperative systems with relatively simple technical solutions based on mobile and smart phones, for example:

- A public service number for bCall, comparable to the 112 emergency service number.
- An application for bCall on nomadic devices to report a non-emergency incident in addition to, or as an extension of, eCall.
- Collect the information via a service or social media.

Here we assume that this information can be made available to the road operator for incident detection, similar to other floating car data, and that this can be organised by 2020.

Guestimates for the performance specifications are collected in Table 46 and motivated below.

Table 46: Guestimates for manual breakdown detection performance on Nomadic Devices

Performance criterion		*Estimate*
PEV_{NDB}	Penetration rate of vehicles equipped with a nomadic device with an breakdown application	25%
DR_B	Detection Rate of manual breakdown reports	70%
DT_B	Detection Time with manual reporting and cellular network communication via a service provider with priority	< 2 min
FAR_B	False Alarm Rate for accidents	$5\% * IR_B * DR_{NDB}$
LA_B	Location accuracy of on-board positioning	LA_{ND}

Penetration Rate

Currently, there are several applications on the market, each with a small market share. It can be expected that the market will concentrate more when these apps become successful. Therefore a penetration rate of 25% by 2020 is assumed.

Detection Rate

The detection rate is defined as the ratio of breakdowns and rescue services requested manually, either from the broken down vehicle or other users. Additionally, other users may also report stranded vehicles like in Waze [15]. Assuming that eventually a manual event will be generated by any one of the passing equipped vehicles within the 2 minutes after occurrence, and then the detection ratio can be higher.

Detection Delay

It will take some time for vehicle occupants to realize a breakdown and report this via an application on e.g. a smartphones. It is likely that data must be obtained through third party service providers which will increase transmission and processing time. The delay is estimated to 2 minutes.

False Alarm Rate

Since breakdown detection is not expected to work automatically, the FAR is determined by false manual reports:

$FAR_B =$ 0.98 [false alarms / year / km] on motorways

0.39 [false alarms / year / km] on secondary roads

Annex 1.3.3 Extraordinary Congestion

Different types of data can be provided by a service provider (or NRA as a service provider) from Nomadic Devices for congestion detection; individual device detections, traffic data, travel time and vehicle tracking data.

Detector Accuracy

The GNSS speed signals sent by smartphones are the major indicator for detecting congestion. The accuracy can be high but it depends on GPS signal quality.

Detection Delay

Detection delays are similar to those from (x)FCD systems. Detailed studies are not yet available.

Detection Rate

Generally, the higher the penetration of equipped vehicles, the better is the detection rate for congestion. However, it is proven that also a minor penetration ratio leads to satisfactory detection rates for congestion. Even with a low penetration rate, a high detection rate of incidents is feasible if the data from the nomadic devices is used directly for Automatic Incident Detection or moving jam detection (e.g). If traffic and travel time data is provided as a service, then congestion and stationary jams can be detected with a high DT as well.

False Alarm Rate

Nomadic devices used for detection of congestion may have similar false alarm rates to those of (x)FCD systems, since GNSS is the major data source.

Table 47: Performance criteria for traffic data from services using nomadic devices

Performance criterion		*Estimate*
PEV_{SP}	Penetration rate of nomadic devices used for a traffic data service	5%
LA_{SPTD}	Location Accuracy of traffic data, which equals the road segment length for which averaged traffic data is provided	100 m
DA_{SPTD}	Detection accuracy of traffic data (average speed)	+/- 10 km/h
DT_{SPTD}	Detection Time of traffic data from service provider, which is the sample time at which the service provider sends updates of traffic data	3 min

Table 48: Performance criteria for positioning and vehicle tracking from nomadic devices

Performance criterion		*Estimate*
PEV_{NDT}	Penetration rate of nomadic devices used for positioning and tracking	5%
DR_{NDT}	Detection Rate of positioning and tracking by nomadic devices	$\approx PEV_{NDT}$
DT_{NDT}	Detection Time of positioning and tracking by nomadic devices + communication and processing time by the service provider	> 10 sec
DF_{NDT}	Detection Frequency of positioning and tracking	< 0.1 Hz
LA_{ND}	Location accuracy of positioning and tracking by nomadic devices	+/- 5 m

Annex 1.3.4 ssessment

Table 49: Performance of Nomadic Devices

	Accidents	Breakdowns	Congestion	
			Tracking for AID	FCD, Travel Time, Traffic Data for stationary jam detection
System Configuration	$PEV_{NDA} = PEV_{NDB} = 25\ \%$		$PEV_{NDC} = 5\%$	
Detection Rate	Medium (70%)	Medium (70%)	High	High
Detection Time	High (2 min)	High (2 min)	High	Very High
Location Accuracy	Medium (+/- 5 m)		Medium	Low
Vehicle class & Dangerous goods	No			
False Alarm Rate	High	High	Medium	Medium
Suitability	Medium	Medium	Medium	Medium

Table 50: Costs of Nomadic Devices

	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€		N/A
Maintenance	€		
Operations	€€€ for accidents and breakdowns		
	€ for congestion		

Annex 1.4 Scanning Radar

Already commonplace in the other industries such as security (automated CCTV surveillance) and aviation (navigation of unmanned transit vehicles), the full scanning potential of radar can be harnessed as an incident detection technology.

During 2008, the Highways Agency (UK) undertook an on-road trial of a full scanning microwave Radar system as a solution for direct detection of incidents [46]. This system constantly performs full 2d Radar scanning and captures dynamic vehicle ‘tracks’ in real-time.

The trial demonstrated that this system can perform accurate tracking over substantial distances (>500m in all directions) which can identify stationary vehicles.

The ultimate performance of this technology is restricted by the obscuration issues (due to line of sight) common to all Radar based technologies. At any time, the radar can only detect the first ‘object’ in the direct line of sight for any given dimension. This has the following limitations:

- Estimation of traffic flow is limited and prone to inaccuracy (therefore it is not particularly suitable for detection of congestion / prediction of flow breakdown).
- Individual vehicle tracks can be lost due to the trajectories of other vehicles; this introduces potential for false alarm if a track is ‘lost’ or missed incidents if a lost track is not raised as an alarm. The likelihood of this is increased (and hence system performance impacted) during peak times / periods of congestion when there are an increased number of ‘tracks’ targeted.

Following this successful trial, the Highways Agency have implemented a full scanning microwave Radar system for incident detection within the Hindhead Tunnel on the A3 in Surrey (England) with construction completed during 2011 [47].

System Configuration

- System configuration specific for accident and breakdowns
- Spacing every 500m for high DR, or 1000m with DR of 50%
- Mounting on existing poles near road side, on gantries above road side or in the middle divider of the road. Sensor mounted at 2 – 8 m above the road (typically at 4 m at Hindhead).

Detection Performance

Detection performance of the scanning radar is assessed in [46].

- Within a range of 300-350m (total coverage of 600-700m) gives detection rate of 90% in low volume traffic with lane accuracy. No lane accuracy beyond this range and up to a range of 500m
- The effective range reduces due to occlusion in high density traffic.
- FAR estimate (1-2 per 8 hour)
- The detection performance is not significantly degraded by adverse weather or light conditions, such as fog or rain.

Setup considerations and costs for a new system

Setup costs for a new system are high in absolute terms but could be described as fairly low if considered relative to comparable systems such as video, but more expensive than cooperative road side units. This is because detector spacing can be greater and also because detectors can be installed with limited infrastructure (using wireless communications) and minimum disruption (which means no need for closures).A scanning radar costs in the order of 10 k€ and a processing unit for processing up to 10 radar inputs costs in the order of 10 k€.

Setup considerations and costs for retrofitting an existing infrastructure

There is high potential for retrofitting the system to existing infrastructure since limited infrastructure is required for installation; communications can be wireless, and radar location is flexible. However it perhaps doesn't reduce the overall capital cost significantly.

Use/upgrade of existing system

Scanning radars are distinctly different in technology/functionality from radar based classifiers that are currently available and commonly used. Therefore installation of a new system would be required and this option is similar to retrofitting an existing infrastructure. .

Maintenance considerations and costs

The technology of scanning radar is proven, albeit in other industries such as security systems, unmanned vehicle navigation systems etc. This means that reliability is not considered an issue, and there are likely to be minimal routine maintenance considerations and costs.

Operational considerations and costs

Operational costs may be relatively higher, however there is the potential to link radar incident alerts to an automated Pan-Tilt-Zoom (PTZ) CCTV camera for fast / effective verification. (Note that this would however increase the setup cost for a new system significantly)

Annex 1.4.1 Accidents and Breakdowns

Table 51: Guestimates for automatic accident and breakdown detection performance of scanning radar

Performance criterion for accident detection		*Estimate*
$DENS_{RST}$	Density of road side equipment	2 radars/km
DR_{A}	Detection Rate of accidents or breakdowns	< 90 %
DT_{A}	Detection Time of accident or breakdowns	< 10 sec
DF_{A}	Detection frequency	>= 10 Hz
FAR_{A}	False Alarm Rate for accidents	6 FA/day/km
FAR_{B}	False Alarm Rate for breakdowns	6 FA/day/km
LA_{RST}	Location accuracy of vehicles	lane accuracy

Detection Rate

The detection rate is limited by line of sight issues associated with radar. The detection rate will be influenced by the traffic conditions and incident location (for example, the distance from nearest detector will increase the opportunity for obscuration of the line of sight, section 0). The DR of accidents within 100m range is about 90% [46].

Detector Accuracy

Scanning radar can detect single stationary vehicles with high spatial resolution.

Detection Delay

The detection delay is very low - detection of stationary vehicles can be instantaneous.

False Alarm Rate

Scanning radar is potentially subject to false alarms in extreme conditions as vehicles are subject to stop/start conditions. This can be mitigated by introducing a minimum stationary time criteria, but this will in turn limit the detection delay and detection rate (leading to increased chance of obscuration).

Annex 1.4.2 Extraordinary Congestion

Table 52: Guestimates for congestion detection for scanning radar

Performance criterion		*Estimate*
$DENS_{RST}$	Density of RIS for vehicle tracking	1 radar/km
DR_{RST}	Detection Rate of traffic jams	> 99 %
DT_{RST}	Detection Time of traffic jams	< 1 min
DF_{RST}	Detection frequency	*> 10 Hz*
FAR_{RST}	False Alarm Rate for traffic jams	low
LA_{RST}	Location Rate of traffic jams	< 100 m

Detector Accuracy
Scanning radar can produce (subject to line of sight limitations) dynamic individual vehicle tracks with excellent spatial resolution.

Detection Delay
The delay is potentially low as individual vehicle tracks can be produced in real time.

Detection Rate
The tracks for obscured vehicles may be lost; hence the accuracy of traffic data is limited, particularly in periods of high traffic flow / congestion.

False Alarm Rate
Algorithms that are based on speed or occupancy may function as desired, however flow based algorithms may be impacted by limitations in the accuracy of traffic data.

Annex 1.4.3 Assessment

Table 53: Performance assessment of Scanning Radar

	Accidents	Breakdowns	Congestion
System Configuration	$DENS_{RST}$ = 2 radars / km		1 radar / km
Detection Rate	High (<90%)		Very High
Detection Time	Low (< 10 sec)		Medium
Location Accuracy	High (1 m)		Medium
Vehicle class & Dangerous goods	No		
False Alarm Rate	High		Medium
Suitability	High	High	Very High

Table 54: Cost assessment of Scanning Radar

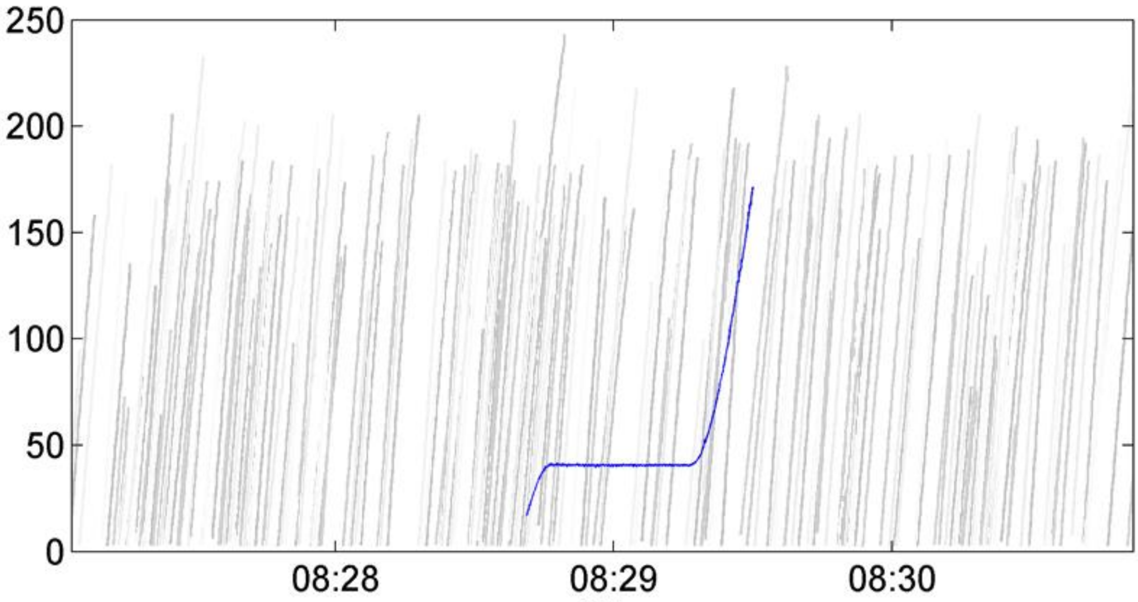
Costs	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€€€	€€	€€
Maintenance	€		No additional maintenance
Operations	€€€ for accidents and breakdowns		No additional operations costs
	€ for congestion		

Annex 1.5 Video Tracking

Video tracking is a technology to detect and track vehicles in real time from a video camera. Every video frame is processed in real time to detect every vehicle in view of the camera. Depending on the camera position, this allows to accurately measure the longitudinal and lateral position of the vehicle on the road, and identify the occupied lane and vehicle class.

The detections from a single vehicle are collected from successive video frames to construct the track of the vehicle over time (Figure 7). This allows to measure the vehicle's speed profile and longitudinal and lateral manoeuvres such as car following, hard braking and vehicle stops lane changes and overtaking, and when vehicles move to the hard shoulder or refuge area (e.g. [17]). Since all vehicles are tracked continuously, any conflicts in vehicle trajectories and accidents can be detected, such as (near) collisions in longitudinal and lateral direction, tailgating (e.g. [16]).

Traffic data can also be aggregated from the individual vehicle data, such as the average speed, traffic flow and density, and perturbations in traffic such as moving traffic jams and stop and go traffic.



Vehicle tracks as lines of vehicle distances from the camera [m] (vertical) versus time [hh:mm].

The track of the vehicle that briefly stops on the hard shoulder (red encircled on the right around 08:29) is shown in bold.

Figure 7: Detection of stopping vehicle from video tracking (from [16]).

System Configuration

The configuration of a video camera system is critical for the performance of tracking vehicles. There is a wide variety of camera types available and their characteristics are largely decisive for the detection range (resolution and view angle) and sensitivity for variations in lighting and weather conditions. Cameras can be mounted in various ways. For monitoring accidents on running lanes, cameras can be mounted above the lanes on gantries, on high buildings or on high poles at the side of the road. The latter configuration is favoured for monitoring vehicles on the hard shoulder.

Detection Performance

The mounting of the camera determines the effective detection area, and the detection rate and false alarm rate. Cameras should be mounted as high as possible to reduce occlusion (section 0). Experience [16] shows that with cameras at the side of the road, on 10 m high poles, individual vehicles can still be distinguished for more than 150 m from the camera in low to medium density traffic. This reduces to 100m in dense traffic and below 80 m in traffic jams. For detection algorithm was tuned for an optimum with a detection rate of 80% of the stationary vehicles with 0.01 false alarms per hour per camera with 10 frames per second (10 Hz). This results in an average FAR of 1 false alarm per 4 days per camera or 2.5 FA/day/km (see Figure 2 for the relation of DR, DT, and FAR). This optimum is also suggested as an acceptable limit in [3] and for rating FAR (section 0). However, the system could also be tuned to reduce the FAR in favour of the DR or DT.

It should be noted that [16] established a ground truth of all stopped vehicles, not just the breakdowns that were officially registered for the statistics used in section 2.4 and as used in the estimation of the FAR for vehicle-based technologies. This results in much higher false alarm rates than the estimates for vehicle-based technologies in Annex 1.1, Annex 1.2, and Annex 1.3.

The effective detection range would increase if the cameras would be mounted higher. In Annex I from [3] a system is presented using existing CCTV cameras on 12 m high poles every 500 m covering a road with 3 lanes and the hard shoulder. The system detects decelerating vehicles, slow-moving and stopped vehicles. From practical experience with the system, a FAR of 10% of the alarms per camera is observed and the availability of the system is 99.8 %. The high FAR is directly related to the large road segment of 500m covered by a single camera.

Occlusion leads to track loss; i.e. the occluded vehicle can no longer be tracked. The consequence is that a lost vehicle can no longer be tracked for accidents or stopping. This would reduce the detection rate, if the event cannot be observed or inferred from other tracked vehicles. The FAR would not increase however.

The performance is affected by weather conditions that reduce the visibility, such as fog and heavy rain or snowfall. In worst case, the reduced visibility range would prevent sufficient detections beyond that range, leaving the remaining part of the road uncovered. The visibility range is an important factor to determine the camera distance.

Another issue for some commercial systems are fast changing light conditions, for example due to passing clouds on sunny days and during sun rise and fall. Most of these issues can be alleviated with image enhancing algorithms [16], but that requires sufficient processing power which is usually not available on existing hardware of traffic monitoring products.

Setup considerations and costs for a new system

A complete new system would require the installation of poles or gantries, cameras, fixed communication network, and video processing units at the road side or in central stations. A cameras and processing units would cost about 4 k€ [3]. The installation of the poles or gantries, and the fixed field communication network is the larger part of the installation costs. The fixed network is required for the video streams to the traffic control centre, e.g. for incident verification. Alternatively, if only the incident detections from the local processing unit can also be sent via Wi-Fi or 3G, then the field communication network could be omitted.

Setup considerations and costs for retrofitting an existing infrastructure
When retrofitting a system with an existing infrastructure, with gantries and a communication infrastructure, then only the additional costs are required for the cameras and video processing units.

Use/upgrade of existing system
For systems with existing CCTV cameras, the video processing hardware and software could be upgraded with more advanced detection of accidents and breakdowns as in [3].

Maintenance considerations and costs
Video camera systems require regular maintenance to clean the camera lenses and adjust or calibrate the camera once a year.

Operations considerations and costs
Operational costs for alarm handling and validation are minimal. The cameras can also be used to verify incidents without additional costs.

Annex 1.5.1 Accidents and Breakdowns

Table 55: Guestimates for automatic accident and breakdown detection performance of video tracking

Performance criterion for accident detection		*Estimate*
$DENS_{RST}$	Density of road side equipment	10 cameras/km
DR_A	Detection Rate of accidents or breakdowns	>80 %
DT_A	Detection Time of accident or breakdowns	< 10 sec
DF_A	Detection frequency	>= 10 Hz
FAR_A	False Alarm Rate for accidents	2.5 FA/day/km
FAR_B	False Alarm Rate for breakdowns	2.5 FA/day/km
LA_{RST}	Location accuracy of vehicles	1 m (lane accuracy)

Annex 1.5.2 Extraordinary Congestion

Table 56: Guestimates for congestion detection for video tracking

Performance criterion		*Estimate*
$DENS_{RST}$	Density of RIS for vehicle tracking	4 cameras/km
DR_{RST}	Detection Rate of traffic jams	> 99 %
DT_{RST}	Detection Time of traffic jams	< 1 min
DF_{RST}	Detection frequency	*> 10 Hz*
FAR_{RST}	False Alarm Rate for traffic jams	low
LA_{RST}	Location Rate of traffic jams	< 100 m

Annex 1.5.3 Assessment

Table 57: Performance assessment of Video Tracking

	Accidents	Breakdowns	Congestion
System Configuration	$DENS_{RST}$ = 10 cameras / km		2 cameras / km
Detection Rate	High (> 80%)		Very High
Detection Time	Low (< 10 sec)		Medium
Location Accuracy	High (1 m)		Medium
Vehicle class & Dangerous goods	Dangerous goods by manual inspection of video		
False Alarm Rate	Medium		Medium
Suitability	High	High	Very High

Table 58: Costs assessment of Video Tracking

Costs	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€€€€	€€€	€€
Maintenance	€€€	€€€	No additional maintenance
Operations	€	€	No additional operations costs

Tolling Systems

In Europe, several tolling systems exist that vary in their technical and organizational aspects. The most common implementations during the last decades have been Electronic Toll Services (ETS), either with satellite-based positioning or gantry-(beacon-) based systems. The main requirements for the implementation of ETS are to operate as a free-flow system and as a multi-lane system. Hence this requires the installation of both road-side sensors and on-board units (OBU) in order to collect data for vehicle detection, identification and classification. Detectors in ETS come with very reliable and accurate measurements on cross-sectional parameters. By the re-identification of OBUs the tolling system allows to gather accurate travel times and traffic flows (vehicles with OBU) for each section. These requirements to operate tolling systems allow additional use of traffic data for incident detection.

The European Commission has published the directive (2004/52/EC) European Electronic Toll Service (EETS) [48] to realize technological and organizational interoperability between different national toll collection systems.

In 2004, the Austrian motorway operator ASFINAG introduced an ETS system on all Austrian motorways for heavy goods vehicles (HGV) with more than 3.5 tons permissible total weight. Toll payments are controlled using toll gantries that are located approximately in the middle between the on- and the off-ramp of each motorway section. Data of the approximately 800 toll gantries are collected in a central system, and provide a nearly complete picture of single HGV trips (including large buses) on the Austrian motorway network with about 4,200 km of carriageway.

HGVs constitute a fraction of total traffic flow between 5% and 30% during a typical working day. The remaining vehicles, which are not observed by the ETS system (light goods vehicles, passenger cars (PCs), etc.), constitute the major fraction of traffic with a dominant influence on traffic density and traffic performance. Furthermore, most HGV vehicles have a limited speed range due to their legal speed limit compared to PCs. HGVs for example have a speed limit of 80 km/h on all Austrian motorways and a lower speed limit on some intra-urban motorways. Based on tolling data mean velocities for each tolling section and traffic flow of HGV can be measured [49].

In addition to the charging data on every toll gantry, cross-section based traffic data such as mean velocity and traffic flow are collected at special toll stations, so-called enforcement gantries. These data exist both for HGV and PCs, thus enabling comparisons between traffic behaviour of HGV and PC traffic.

Velocity values of HGVs and PCs have similar behaviour in congested situations. As traffic density increases, PC and HGV traffic speeds increasingly converge.

This functional relationship can be directly observed at local measurement stations. Best results for detecting incidents (congested situations), estimating travel time, and performing traffic prediction could be achieved by combining different measurement methods (local and section-related). With current available travel time measurements it is not feasible to detect accidents of broken down vehicles.

Only extraordinary congestion can be detected directly (with time delay). Travel time measurements are not feasible for detection of incidents with individual vehicles such as a broken down vehicles or accidents

Annex 1.5.4 Extraordinary Congestion

In [50] a tolling systems is described that is also used to estimate travel time and congestion (Table 59). Tolling systems use a diversity of sensor systems to identify the vehicles including vehicle class. Sensor systems are typically located at particular toll locations. The detection systems are monitoring vehicle presence not vehicle speeds. The spacing between detection points is large, i.e. the entrance and exit ramps to the toll road. Normally there are no detection points for traffic between the toll locations, so travel times are only determined for vehicles leaving the toll road. The data from tolling systems can therefore only be used for travel time estimation, with a considerable delay. Congestion can be derived from a significant increase in the average travel delay.

Detection Performance

The most common implementations of tolling systems during the last decades have been ETS for heavy good vehicles on motorways, operating at free flow and multi-lane systems either with satellite-based positioning or gantry-(beacon-) based localization. This requires the installation of both road-side sensors and in-vehicle units in order to collect toll data.

Therefore the most relevant criteria for incident detection performance are:

- the system configuration, e.g. satellite-based positioning, “closed systems” with detection at each on/off ramp or others
- the percentage of vehicles to pay tolls and equipped with OBU
- the network structure, e.g. gantry spacing
- communication technology, data warehouse and time delay

Table 59: Performance parameters of travel time measurement systems from tolling systems (see also Table 11 and Table 28)

Performance criterion		*Equation*
$DIST_{TT}$	Distance between detector locations	10 km
DR_{TT}	Detection Rate of vehicles identified at begin and end location	> 95%
DT_{TT}	Detection Time of travel time delays ($DIST_{TT}$ / V_{avg},)	> 8.6 min
LA_{TT}	Location accuracy of incident ($DIST_{TT}$)	$DIST_{TT}$
DT_C	Detection Time of congestion (DT_{TT} + 0.5* ΔTT)	> 10.75 min
LA_C	Location accuracy of incident (LA_{TT})	10 km

System Configuration

Tolling sections are designed based on the network structure and the on and off ramps. Electronic Tolling Systems are designed to realize data collection from OBUs, data communication within the system and computation of toll charges. Calculation of traffic data and the use for incident detection is a secondary effect. System configuration specific to ETS:

- Mounting and installation options (e.g. overhead above lane on gantries)
- Geographical spacing of gantries (e.g. in Austria the average section length is 4.9 km, with a maximum of 10 km)
- Obligation to pay tolls (the percentage of vehicles to pay tolls and equipped with OBU, e.g. toll for HGV in Austria: 5% to 30% of total traffic flow)
- Communication technologies and policy (e.g. communication delay and storage policy)

Detection Rate

The specifications for the penetration rate of on-board units for ETS is higher than 99%. On tolling systems for HGVs only, as in Austria, where 5 to 30% of traffic are HGVs, the penetration rate of vehicles providing travel time information is sufficient for congestion detection in high volume traffic. A detection rate of traffic jams is estimated to be larger than 80%.

Detector Accuracy

The spatial accuracy for identifying extraordinary congestion is defined by section size. The system can give indicators by time delays (e.g. in travel times or a rapidly decreasing traffic flow) but no exact position for an incident. Stationary traffic jams and congested traffic can be detected.

Detection Time

Detection delay is caused by section length and delays in communication and data handling. Tolling systems identify vehicles by their OBU signature at the tolling stations at the entry and exit of the tolling section. The tolling data for a section is complete, if the vehicle is passing the second toll gantry and leaving the toll section.

Typically delays in congestion detection and alarming an operator are extended with the travel time of sections, which depend on the section length, speed limits and distribution of passenger cars and HGVs. For a 10 km section of motorway, normal travel times may vary between 4 and 8 minutes for passenger cars and HGVs. With an additional time margin for variations due to other environmental factors, the detection time can be easily 10 min longer than for a conventional system with inductive loops at 500m spacing.

False Alarm Rate

Electronic Tolling systems are designed to work 24/7 with robust technologies against external factors, like different traffic flows and weather conditions. False alarms are generally caused by the congestion detection algorithms (sensitivity and thresholds). Therefore the FAR will be similar or lower than for travel time based congestion detection systems such as inductive loops or Bluetooth detectors.

Costs considerations for upgrading an existing system

For a completely new system the set up costs would be very high for infrastructure (e.g. gantries/beacons, OBUs, IT infrastructure, enforcement system) and needs road closures for installation (partly closures). Therefore tolling systems are not recommended to set up as a new system for incident detection.

An existing ETS can be easily extended with congestion detection. The detection algorithm can reuse the tolling data and no further infrastructural adaptations would be required. The assessment below only considers the costs for upgrading an existing system for incident detection. As an ETS is in operation, the additional setup and maintenance costs for software are minor.

Maintenance considerations and costs

Tolling systems use a variety of sensor technologies, usually including video cameras. Maintenance is therefore comparable to that for video tracking, albeit that the cameras are only located at the tolling stations.

Operations - considerations and costs
Tolling systems are only used for congestion detection, for which validation is not required. The handling of the false alarms is expected to be low due to the low FAR.

Annex 1.5.5 Assessment

Table 60: Performance of Tolling Systems

	Accidents	Breakdowns	Congestion	
System Configuration	N/A		Overhead units on every lane at entry and exit toll stations	
Detection Rate			High (>80%)	
Detection Time			High ($DIST_{TT}$ = 5 km)	Very High ($DIST_{TT}$ = 10 km)
Location Accuracy			Low	
Vehicle class & Dangerous goods			Vehicle class only	
False Alarm Rate			Low	
Suitability			Medium	

Table 61: Costs of Tolling Systems

Costs	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€€€€	€€€	€
Maintenance	€€	€€	No additional maintenance
Operations	€	€	No additional operations costs

Annex 1.6 Automatic Number Plate Recognition ANPR

Automatic Number Plate Recognition (ANPR) detects and recognises the license plate of a vehicle. Most systems make use of the retro reflection of license plates. A near infrared or ultra violet flash source at the position of the camera results in a bright image recording of the license plate. The camera can be triggered by another sensor, for example an inductive loop, whereby the camera takes only a photo at passage of the vehicle. Other solutions take 25 to 30 images per second and detect the passage of the vehicle in the video stream.

The detection percentage of ANPR varies between 70% to maximum 98%.

ANPR systems are not suitable for detection of accidents or breakdowns. Potentially, accidents or breakdowns could be inferred from missing vehicles over successive measuring locations. However, this would lead to an acceptably high false alarm rate due to the number of missed vehicles for the given detection rate (section 0).

Annex 1.6.1 Extraordinary Congestion

ANPR cameras are used on a route, the travel time of each individual vehicle can be determined. Congestion can be detected from significant delays in travel time, but with a relative long detection time and poor location precision. ANPR cameras should be mounted overhead, one camera per lane.

ANPR systems are widely used for tolling systems, trajectory control systems and travel time prediction systems. Algorithms for detecting (extraordinary) congestion can be used as described for tolling systems.

Costs considerations

ANPR systems require cameras to be mounted overhead of each lane on gantries, which requires huge setup costs. Retrofitting an existing infrastructure with gantries requires the installation of the cameras and processing. Upgrading existing ANPR systems would require replacement of the cameras and processing units only

Table 62: Guestimates for congestion detection for ANPR

Performance criterion		*Estimate*
$DIST_{TT}$	Distance between detector locations	5 km
DR_{TT}	Detection Rate of vehicles identified at begin and end location	> 70%
DT_{TT}	Detection Time of travel time delays ($DIST_{TT}$ / V_{min})	> 4.3 min
LA_{TT}	Location accuracy of incident ($DIST_{TT}$)	5 km
DT_C	Detection Time of congestion (DT_{TT} + 0.5* ΔTT)	> 5.4 min
LA_C	Location accuracy of incident (LA_{TT})	5 km

Annex 1.6.2 Assessment

Table 63: Performance assessment of ANPR

	Accidents	Breakdowns	Congestion
System Configuration	N/A		Overhead units on every lane Distance = 5 km
Detection Rate			High
Detection Time			High
Location Accuracy			Low
Vehicle class & Dangerous goods			N/A
False Alarm Rate			Low
Suitability			Medium

Table 64: Costs assessment of ANPR

Costs	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€€€€	€€	€€
Maintenance	€€€	€€€	No additional maintenance
Operations	€	€	No additional operations costs

Annex 1.7 Bluetooth detectors

[31] show a penetration rate of BT devices on the motorway between 10-15% in 2011. **Invalid source specified.** measured an average penetration rate of 15% in 2011.

Detection Rate

Sectional data from BT system can only indicate an incident. The detection rate for congestions depends on system design and BT penetration rate (up to 40% of overall traffic).

Location Accuracy

Detection in BT Systems have to deal with:

Multiple detection of BT devices at a single station; Multiple BT devices per vehicle; Inaccuracy in Localization; Outliers, Equipment rates and vehicle classification.

Localization Accuracy of Congestions is defined by the section size.

Detection Delay

Detection of Cross-sectional data is done instantly (q, v). Re-Identification is delayed by the traveltime of the corresponding section (section based data), data communication and processing (depending on network structure).

False Alarm Rate

With the availability of section-based data (traveltimes) of a considerable portion of the overall traffic and adequate algorithms the False Alarm Rate is low for Detection of Congestions.

Cost considerations

Bluetooth detectors are relatively easy to install on short poles or existing constructions anywhere near the road side, and use WiFi communication with the back office or control centre. Setup costs of new systems or retrofitting an existing infrastructure are relatively small. Maintenance costs are minimal; i.e. the detectors do not need regular maintenance expect perhaps for software. The detection system has no means for validation of congestion alarms, but validation is not considered as a requirements for congestion alarms.

Table 65: Performance parameters of travel time measurement systems from Bluetooth detectors

Performance criterion		*Estimate*
$DIST_{TT}$	Distance between detector locations	5 km
DR_{TT}	Detection Rate of vehicles identified at begin and end location	> 50%
DT_{TT}	Detection Time of travel time delays ($DIST_{TT}$ / V_{min})	> 4.3 min
LA_{TT}	Location accuracy of incident ($DIST_{TT}$)	5 km
DT_{C}	Detection Time of congestion (DT_{TT} + 0.5* ΔTT)	> 5.4 min
LA_{C}	Location accuracy of incident (LA_{TT})	5 km

Annex 1.7.1 Assessment

Table 66: Performance assessment of Bluetooth Detectors

	Accidents	Breakdowns	Congestion
System Configuration	N/A		units mounted at side of the road every 5 km
Detection Rate			High
Detection Time			High
Location Accuracy			Low
Vehicle class & Dangerous goods			N/A
False Alarm Rate			Low
Suitability			Medium

Table 67: Costs assessment of Bluetooth detectors

Costs	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€€	€	N/A
Maintenance	€	€	
Operations	€	€	

Annex 1.8 Inductive Loop Detectors

Annex 1.8.1 Extraordinary Congestion

Historically, Inductive Loop technology has provided the de facto system for traffic data collection and congestion incident detection. Inductive Loop technology traditionally consists of a 'loop array' (a coil constructed from loop detector cable) installed within the carriageway. As vehicles pass above the loop array, the inductance of the sensor circuit is altered and vehicle presence detected. Whilst single loop sites are common practice for traffic count sites; the installation of two (spaced upstream and downstream) loop sites within a single lane allows measurement of a wide range of traffic statistics including vehicle speed, length and headway (the time elapsed between initial detection of sequential vehicles).

Many characteristics can affect the inherent sensitivity of an inductive loop, for example:

- Type of detector cable used
- Number of turns within array
- Installation depth
- Length of loop feeder cable
- Connections

To ensure confidence in data used for incident detection (such as occupancy); the sensitivity of an Inductive Loop is configured during installation.

Inductive Loop technology can provide significant insight into the real-time performance of a road network. Data such as vehicle speed and occupancy can identify periods of congestion, whilst monitoring the relationship between traffic flow and speed can help predict the onset and dissipation of congestion.

Central to any such system is incident detection algorithms that monitor network conditions, identify patterns that represent the onset of congestion and trigger alerts accordingly.

- Occupancy, speed or flow based Algorithms – highlight "ordinary congestion" by continually observing the speed/flow on a link and when thresholds are exceeded, the onset of congestion is predicted and an alert is raised accordingly. The principle purpose of this alert is that, with early detection and corrective action (restricting the approach speed of upstream vehicles), flow breakdown can be averted and network efficiency maintained.
- High Occupancy Algorithms – highlight "extraordinary congestion" (that may have resulted either from an incident directly or from other abnormal traffic patterns) by continually observing the occupancy on a link. The HIOCC algorithm is described in further detail in [21]. The HIOCC2 algorithm couples the above process with a vehicle speed cross reference (essentially a logic gate). Any HIOCC alert (that would be raised) is compared against the corresponding vehicle speeds. The alert is then suppressed or raised (as a HIOCC2 alert) as applicable. The HIOCC2 algorithm is described in further detail in [23].
- In the Netherlands about 980 km of motorways are equipped with the Motorway Traffic Management (MTM) system. The MTM system uses 16,830 inductive loops, 243 radar systems, and 14,196 speed limit matrix signs, typically installed about every 500 meters, which are able to detect congestion and inform drivers [51]-Annex B. The Monica (MONItoring CAsco) system collects minute-aggregated speed and flow for each lane. The Automatic Incident Detection (AID) system detects and monitors the tail of traffic jams and automatically warns traffic approximately 1 km upstream of the jam tail. Dynamic traffic signs are installed approximately every 500 metres to warn drivers approaching the tail of the congestion

This approach provides a system that detects the onset of extraordinary congestion with a significant level of confidence to deliver automated response in a timely manner.

System Configuration

The system configuration for detection of extraordinary congestion requires a pair of inductive loops in every lane of the road cross section, and a detector outstations to collect all data from these loops. This loop detection system set up is required at regular distances along the road segment. Typical spacing for the loop detection setup for detection of congestion is 500m or more.

Detector Accuracy
A well installed, well maintained loop provides unparalleled accuracy for detection of vehicle presence and collection of traffic data including: speed, flow, occupancy, headway, vehicle length.

Detection Delay
Loopsite spacing should be designed to provide sufficient data granularity to ensure that congestion algorithms can detect flow breakdown within an acceptable delay.

Detection Rate
Detection rate is good, although detection of incidents can be missed if congestion does not propagate to the next loop site.

False Alarm Rate
False alarms are generally caused by algorithm design (sensitivity and thresholds) and/or inaccuracies from poorly installed / maintained / calibrated loops.

Detection Performance for Automatic Incident Detection

See section 5.3.1.

Table 68: Guestimates for congestion detection for inductive loops

Performance criterion		*Estimate*
$DENS_{RS}$	Density of inductive loop detector stations	Every 500m
DR_{RSP}	Detection Rate of road side point measurement of a single passing vehicle	> 99 %
DT_{RSP}	Detection Time of road side point detections of a single passing vehicle	< 10 sec
DA_{RSTD}	Detection Accuracy of traffic data (average speed)	+/- 10 km/h
SW_{RSTD}	Sampling time window or moving window over which traffic data is averaged per sample.	1 min
DT_{RSTD}	Detection Time of traffic data is the sampling time.	1 min
DR_{C}	Detection Rate of congestion incidents	> 50 %
DT_{C}	Detection Time of congestion	< 10 min
LA_{C}	Location accuracy	500 m

It is crucial to note that performance of inductive loops is dependent on the calibration. In addition, the performance estimates above do not take into account consideration of the availability of inductive loops – maintenance of loop sites is of critical importance in achieving the potential performance.

Setup considerations and costs for a new system
Setup costs are high for a new system as road access (closures) is required for installation, and inductive loop pairs have to be cut in the road pavement on every lane and at regular distances along the road, for example every 500m. Installation and calibration are of critical importance as inclement weather will adversely impact installation and a poorly calibrated loop will introduce systematic errors to occupancy, speed, vehicle length and flow.

Maintenance is also of critical importance. A well installed loopsite can be very reliable and accurate, however a poorly installed loopsite can be inaccurate and prone to failure. Loop replacement requires road access (closures) and therefore maintenance costs can be high.

For congestion purposes, system can perform in a fully automated manner so operational costs are low. For accident / breakdown purposes, the operational costs depend on the ease of incident verification.

Setup considerations and costs for retrofitting an existing infrastructure
As loop arrays are installed into the carriageway and do not require other civil infrastructure, there is limited opportunity for efficiency savings through retrofitting to existing infrastructure.

Maintenance considerations

Inductive loop detectors require frequent maintenance for calibration, e.g. due to road surface deformations and may need to be replaced when the road surface is repaired.

Operations considerations

An inductive loop system has no means to verify an automatic incident detection, so potentially another system (e.g. CCTV cameras) is required or manual verification is needed.

Annex 1.8.2 Accidents and Breakdowns

Current inductive loop technology is not a feasible option for detection of accidents and breakdowns through individual vehicle tracking.

However, there has been a recent development in the use of Inductive Loop technologies that could prove of significant benefit to the application of incident detection in the future. This development is described here for information only.

The conventional approach to inductive loop detectors is based upon discrete detection of presence (yes/no). Although this is perfectly valid for traffic counting sites, this approach introduces a reliance on calibration of the loop sensitivity (dL/L) to yield accurate measurements for other traffic data. This issue is further compounded when considering a two – loop speed measurement installation, whereby differences in sensitivities of loops 1 and 2 will have adverse effect on the speed measurement (which is inferred from the delay between presence detection at each loop site). These issues highlight the importance of competent installation and effective maintenance of inductive loop sites to ensure the practicability for incident detection. In consideration of these issues, a potential enhancement has been presented from the tolling/shadow tolling industry where accurate measurement of vehicle classification is of critical importance. Technologies have been developed that not only detect presence, but process and analyse the entire inductance pattern of the vehicle detected. This offers two significant benefits.

Firstly, through wave pattern analysis, sequential inductive loop sites can self-regulate to negate the negative effects of variations in loop sensitivities. Secondly, through wave pattern matching, multiple speed measurements can be made for any vehicles using uniquely identifiable characteristics of the inducted wave pattern (such as spikes, peaks, troughs etc.). Using these two enhancements, the system can self-correct for loop sensitivity variation and provide key traffic data (such as speed, occupancy and vehicle length) to a significantly increased accuracy.

During 2008, the Highways Agency (UK) undertook trial of an on-road trial of such a system for the purpose of incident detection [46]. Study findings and subsequent research has demonstrated that the accuracy of the traffic data is significantly enhanced.

Furthermore, a significant finding was that such a system demonstrated potential to provide vehicle tracking (from wave pattern matching) such that individual vehicles could be identified if missing (for example in the event of an incident between loop sites). This trial highlighted limitations for this application of the technology with performance significantly deteriorating (decreased detection rate, increased false alarm rate) as a result of a number of factors:

- Traffic conditions – during peak times (high flow) reduces confidence in transit time and impacts performance
- Loop spacing – increased spacing of loops reduces confidence in transit time and impacts performance

Annex 1.8.3 Assessment

Table 69: Performance assessment of Inductive Loop Detectors

	Accidents	Breakdowns	Congestion: AID	Congestion: Stationary jams
System Configuration	Pairs of loops on every lane at a distance of 500m			
Det\ection Rate	Low		Medium	High
Detection Time	High		High	High
Location Accuracy	Low		Low	
Vehicle class & Dangerous goods	Vehicle class			
False Alarm Rate	Very High		Medium	Medium
Suitability	Low		Low	High

Table 70: Costs assessment of Inductive Loop Detectors

Costs	New System	Retrofit to existing infrastructure	Use/upgrade of existing system
Set Up	€€€€	€€€	€
Maintenance	€€€	€€€	No additional operations costs
Operations (congestion)	€	€	No additional operations costs
Operations (incident verification)	€€€	€€€	No additional operations costs

Annex 2 Guidance for demonstration of Business Case

The objective of the business case is to provide justification for system development and/or procurement. The business case should provide quantitative appraisal and demonstrate the balance between system costs and system benefits Figure 8.

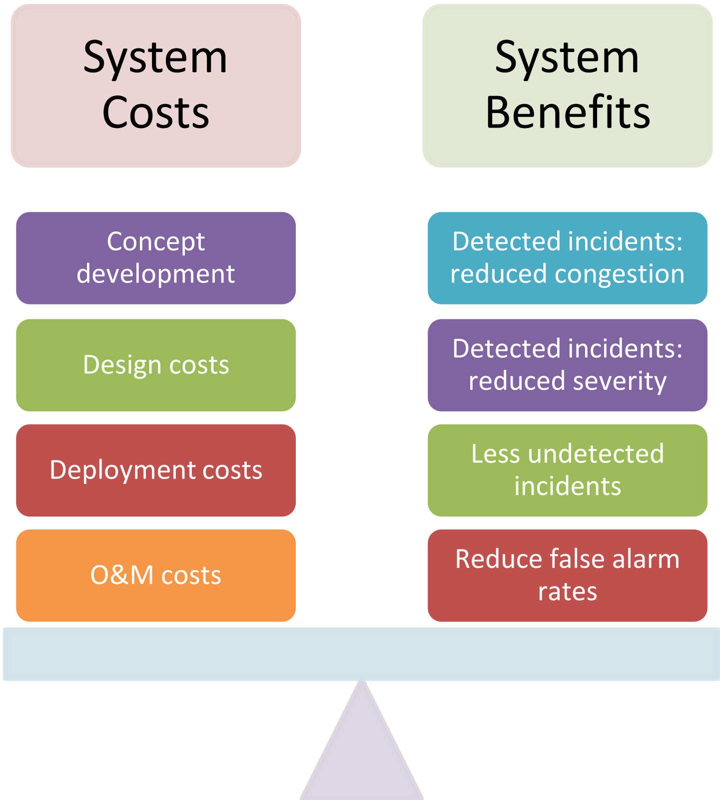


Figure 8: Balance between system costs and system benefits

This section provides generic guidance for the quantitative demonstration of a business case for an incident detection system. Specifically, Annex 2.1 provides guidance estimating systems benefits whilst Annex 2.2 provides guidance for evaluating systems costs.

Annex 2.1 System Benefits

Annex 2.1.1 Generic approach to estimating system benefits

The generic approach to estimating system benefits can be described in terms of reducing three cost elements:

(i) Cost of detected incidents
(ii) Cost of undetected incidents
(iii) Cost of false alarms

The scheme for the generic approach to improve system benefits is sketched in Figure 9 and explained in the following sections.

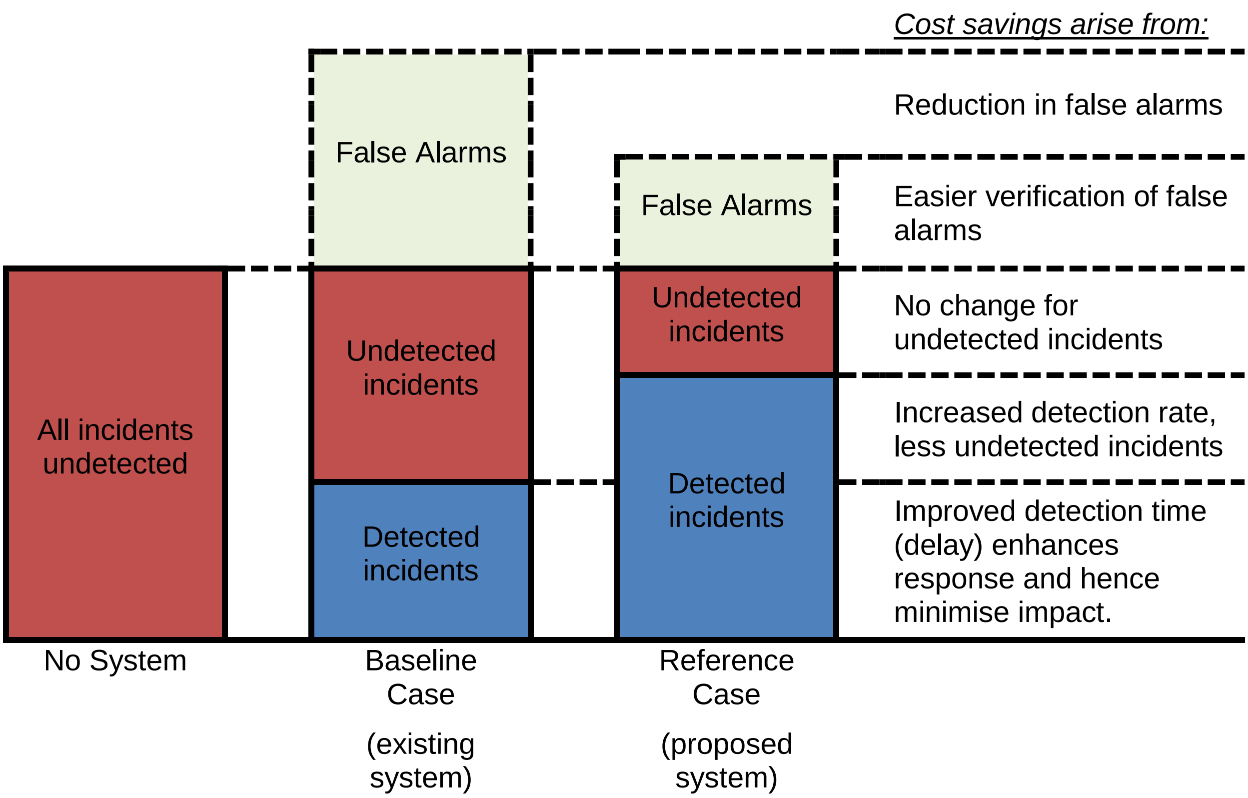


Figure 9: Scheme for the generic approach to estimate system benefits

Annex 2.1.2 Cost element of detected incidents

Cost element of detected incidents will be influenced by the relative detection times (and associated impact on congestion) of the reference (considered) and baseline (existing) systems.

The cost element of detected incidents is composed of two distinct components:

(a) Indirect cost component due to incident related congestion
(b) Direct cost components due to accident, cost of damage, cost of injuries, cost of response

These two components require consideration in isolation, this approach is described below:

(a) Indirect cost component due to incident related congestion

The total cost component for congestion for detected incidents will be based upon the speed of incident response and the rate at which congestion builds and subsequently dissipates.

It is also noted that the speed of incident response/clearance will actually be a function of the rate at which congestion builds, as the incident related congestion will restrict the ease of access to the incident location (for the emergency services).

A simple approach estimating the rate at which congestion will build or dissipate is to consider that traffic flow and the number of lanes available for road users. Speed flow relationships can be used to approximate the reduced approach speed; and should the demand exceed 1800 vehicles per hour per lane, it is probable that flow breakdown will occur and congestion will propagate in a direct relationship with demand.The cost of congestion can be estimated by considering the cost of a single vehicle delay (for example per car per minute) and then multiplying by this by the amount of congestion.

A simple way of achieving this is by considering the impact on flow over the duration of the incident. If a distance-flow plot of the incident location is considered, there should be a clear difference actual flow and the anticipated travel demand.

Cost savings: how many minutes of delay are saved and for how many vehicles, multiplied by the cost of time.

(b) Direct cost components due to accident

The direct cost components due to the accident are somewhat more complicated to estimate:

Cost of damage: infrastructure and vehicles – This can be assumed as zero, i.e. the accident will occur with or without the incident detection system. (Although it should be noted that systems may reduce the likelihood of secondary accidents.)

Cost of injuries: this is a very contentious issue that is difficult to estimate in a quantitative manner, however it is clearly recognised that quick and efficient response will significantly improve the time for access to emergency services and medical attention, and may potentially mitigate the accident severity.

By attributing a cost to each incident severity, a cost comparison can be made between different cases (of different detection delay), this can be assigned as the direct cost component due to accident.

Therefore the total cost savings element of detected incidents can be estimated by combining the congestion related savings and the accident related savings and multiplying this by the number of successfully detected incidents, i.e.

Cost element of undetected incidents

Although undetected incidents will have a negative impact, the cost savings are due to the increase in detection rate (from the new system). In other words, some costly undetected incidents will have become detected and manageable incidents.

Therefore, the costs savings associated with undetected incidents will be influenced by the relative detection rates of the reference (considered) and baseline (existing) systems.

Undetected incidents would have an inherent cost disbenefit; if an undetected incident in the baseline case would remain undetected by the reference system, the same cost disbenefit will be realised. Therefore, within a business case, these incidents will be cost neutral.

Incidents that will be missed (undetected) by both systems (reference and baseline) do not provide any cost benefit component (positive or negative).

Cost savings: how many currently undetected incidents will be detected by the reference system, multiplied by the cost savings of these detected incidents (compared to such incidents being undetected).

Cost element of false alarms

Cost element of false alarms: is described as the operational costs associated with false alarms, this is influenced by the relative false alarm rates (and associated effort in alarm verification) of the reference (considered) and baseline (existing) systems.

In undertaking this evaluation it should be ensured that the incident frequency and false alarm rate are both normalised to the same time and distance baseline (i.e. incidents/false alarms per kilometre day).

Annex 2.2 System Costs

Although estimation of the system costs is perhaps more straightforward, it is important to identify costs incurred throughout the system development lifecycle. The template below lists tasks that are carried out within the lifecycle that may have a cost associated.

Template for consideration of system costs			
Phase	Task	Action	Cost
Concept Development	Feasibility Study	Estimate frequency of incidents considered	
		Estimate impacts of incidents considered	
	Concept of operations	Capture user requirements	
		Understand incident response	
System Development	Requirements	Capture system requirements	
	System Specifications	Performance specifications for sensors	
		Performance specifications for algorithm	
	New system?	Bespoke or off the shelf?	
	Sensor	If bespoke; development, testing & approval	
	Algorithms	If bespoke; development, testing & approval	
	Hardware	If bespoke; development, testing & approval	
Design	High Level Design	Quantity of sensors	
		Location of sensors	
	Detailed Design	Instation equipment	
		Outstation equipment	
		Hardware	
		Software	
		Communications	
		Power	
		Civils infrastructure	
Deployment	Equipment and installation costs	Instation equipment	
		Outstation equipment	
		Hardware	
		Software	
		Communications	
		Power	
		Civils infrastructure	
		Traffic Management	
Testing and	Acceptance	Factory Acceptance Testing	

Acceptance	Testing	Site Acceptance Testing	
		User Acceptance Testing	
Operations and Maintenance	Operations	Routine monitoring	
		Verification and validation of alerts	
		Initiate response	
	Routine Maintenance	System monitoring	
		System checks	
		System tests	
		Sensor cleaning (if required)	
		Traffic management	
	Corrective maintenance	Fault identification	
		Fault diagnosis	
		Fault repair	
	Changes and upgrades	Instation equipment	
		Outstation equipment	
		Hardware	
		Software	
Decommissioning		System decommissioning and removal	
Total System Costs:			

Development of a business case involves evaluating whole life costs and savings; this requires consideration of the time value of money.

Time value of money: monetary valuations are not definitive; capital can be invested in savings or opportunities whilst the value of money is subject to variation due to inflation. The time value of money ensures that monetary values can be compared like for like; this is done by "discounting" such that all values are normalised to an absolute value at a fixed time (normally present day).

Note that the business case should not just be an assessment of costs and benefits; it should also document other considerations, including but not limited to:

- Technical and financial risk
- Availability of funds
- Legal issues (e.g. privacy, data protection)
- Risk of organisational changes
- Public perception