RAIDER

User Needs and Requirements for Incident Detection Systems

Deliverable 2.1

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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 is addressing 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 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 February 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 aims to define the user needs and requirements for incident detection systems of Road Authorities as well as their experiences on operational issues and products. It also aims to identify the most relevant incidents and their operational situations for incident detection. The current state of the art of incident detection technology and products, as well as information on user needs and trials on incident detection are being reviewed.

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.

On the basis of the stakeholder consultation three incident types were identified. They are:

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

Report D2.1 describes the three types of incidents, detection systems in use, operational experiences, and the user needs and requirements. Points of consideration include:

- Delay in travel time due to extraordinary congestion is required 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)

- 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
- 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 detection of incidents in tunnels (i.e. below 1 min) is required and is state of the art
- Floating car data, such as nomadic devices, is not commonly used by road operators

Based on feedback from the stakeholders and the literature review, the identified detection systems in use are for:

- Point measurements: inductive loops, radar, video
- Travel time estimation: automatic number plate recognition, Bluetooth scanners,
- Vehicle tracking: radar, video, (nomadic devices)

Performance indicators of the incident detection systems are also investigated. Examples of performance indicators are the detection rate, false alarm rate, detection time and location precision. Performance requirements of incident detection systems should be derived from the incident management chain; detection, verification and response.

Constraints of the operational environment of the incident detection systems should also be taken into consideration; e.g. the false alarm rate that is acceptable depends on the extent of operator interaction required, environmental conditions will influence the false alarm rate.

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Abbreviations

Abbreviation	Meaning
AID	Automatic Incident Detection
ANPR / ALPR	Automatic Number/License Plate Recognition
MIDAS	Motorway Incident Detection and Automated Signalling
E-Call	Pan-European in-vehicle emergency call system
ETS	Electronic Toll Services
EETS	European Electronic Toll Service
HGV	Heavy Goods Vehicles
ILD	Inductive Loop Detector
PSAP	Public-Safety Answering Point
VIN / VIS	Vehicle Identification Data / Vehicle Identification Sequence
WMI	World Manufacturer Index
VIDS / VIPS	Video Incident Detection System / Video Image Processing System
UTC	
GPS	Global Positioning System
DR	Detection Rate (section 4.1)
DT / TTD	Detection Time (section 4.1)
FAR	False Alarm Rate (section 4.1)

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 break-down	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.

1 Introduction

1.1 ERA-NET ROAD II programme

"ERA-NET ROAD II – Coordination and Implementation of Road Research in Europe" is a Coordination Action funded by the 7th Framework Programme of the EC. The partners in ERA-NET ROAD II (ENR2) are United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR2 a joint research programme "Mobility – Getting the most out of Intelligent Infrastructure" is initiated. The funding National Road Administrations (NRA) in this joint research project are Belgium, Switzerland, Germany, Netherlands, Norway and United Kingdom. The main objective of this programme is to improve the management of the European road network. "High quality traffic management/information data and incident detection" is one of the four objectives in this programme addressed in this project.

1.2 Incident management and the quality of traffic data

Across Europe, incidents account for an estimated 10% to 25% of all congestion and are the largest single cause of journey unreliability [1]. "Incident" is a broad term for which different definitions are used. Here we use as a working definition "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" (by analogy from [2]).

Incidents critically limit the operational efficiency of the road network and put road users at risk. A direct effect of incidents is the congestion due to the temporary and sudden lane closures, and consequently a delay in travel time. Another serious problem is the risk of secondary crashes. As an example of the direct effects on congestion, it was estimated in the Netherlands that 13% of vehicle hours lost were directly related to incidents in 2009 [3]. While 80% of these incidents were small and could be solved by road users, 20% lasted longer and heavily influenced throughput.

The objective of incident management is to reduce the effects of incidents, both in terms of throughput and safety. Incident management is a process of the following activities: detection and verification of the incident, providing traveller information and traffic control, alarming emergency and rescue services, scene management, road clearance and recovery [4]. This project focusses on the first step in incident management; incident detection. Incident detection is the process of determining the presence and location of an incident. For the detection of incidents, various information sources can be used, like calls from motorists by mobile telephone or call boxes, and calls from surveillance or emergency teams. This project, however, only addresses the systems for automated incident detection.

Efficient incident management requires close cooperation of many different organisations including the road operators, road authorities, emergency response teams and vehicle recovery teams. The roles and responsibilities of road operators and authorities in incident management evolve while new incident management strategies are being developed, e.g. [1], [4].

In this context, requirements and needs for incident detection and the quality of incident data also evolve. Incident detection is an essential capability for road operators and 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 the efficiency and effectiveness of incident management. High quality of data enables faster resolution of incidents and proactive measures to avoid or minimize traffic disturbance. One of the findings from [1] is that "The most powerful tool in minimising the impact of incidents – and the one that is in the NRA's direct control – is the provision of fast, direct, high-quality information in a standard format that is acceptable across Europe".

1.3 Project objectives

RAIDER is a research project aiming to improve incident detection systems by incorporating new technologies for roadside systems and utilizing in-vehicle systems and nomadic devices. RAIDER investigates how these new technologies can improve incident detection in terms of the quality of the detections, reduce the estimated costs of incident detection systems, and improve the benefits for incident management.

Incidents are most often associated with motorway incidents. The stakeholders in this project, the National Road Authorities and road operators mainly operate motorways, and most incident detection systems are applied on motorways. Hence this project primarily focusses on motorway incidents, although incident detection on secondary roads may also be considered when appropriate.

RAIDER has a focus on near-future technology improvements with a target time horizon for implementation between 2015 and 2020.

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 generic specifications will be developed in the following steps that are divided in two project phases:

Phase 1 – User needs and Requirements:

- Experts from the National Road Authorities are consulted as stakeholders to ensure the necessary focus in the project, to select the top priority types of incidents and most pressing issues as reference cases for research.
- Stakeholders are consulted to assess their operational experiences and issues with existing systems, and to define user needs and requirements for incident detection systems (now and in the future) as a reference for evaluating new technologies.

Phase 2 – Requirements analysis and specifications:

- Quality criteria are derived from user needs and requirements, operational experiences, and issues with the functionality and performance of incident detection systems. Quality criteria can be defined for complete incident detection systems and can also be segregated into criteria for the major system components such as the sensors, data fusion and incident detection algorithms. The final deliverable for this project will provide guidance for how quality criteria can be developed.
- Definitions will be developed for high level system architectures and concepts for incorporating new technologies for roadside systems, or utilising in-vehicle systems and/or nomadic devices.
- Guidance for estimation of costs and benefits will be developed such that member states can undertake appraisal of the suitability and feasibility of new technologies in roadside sensors, or by using nomadic devices and in-vehicle systems.
- Generic specifications will be developed for incident detection systems and their major components (sensors, data fusion and incident detection algorithms) in terms of quality requirements. The purpose of these generic specifications is to provide a pro-forma from which member states can detail specifications tailored to the specific requirements and constraints of the incident detection systems in question

1.4 Report structure

This report presents the results from the first phase; the user needs and requirements.

Experts on incident detection from the National Road Authorities have been consulted as stakeholders to identify the three most relevant types of incidents, to assess their current needs and requirements on system performance. The stakeholders have been consulted via an on-line questionnaire and through interviews. The results on the prioritisation of the types of incidents are reported in section 2. This stakeholder priority will be used as the focus in the remainder of the project. The selected types of incidents are presented in more detail in section 3. In parallel, a literature review was conducted with the same focus. The results from the literature and stakeholder feedback is presented in section 5.

Section 4 introduces a framework for analysing and assessing system performance and its relation to data quality, that will be used in this project to evaluate and assess detection systems and new technologies.

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2 Prioritizing Incident types

The National Road Authorities are the stakeholders for incident detection in this project, and in particular the NRA's within the ERA-NET ROAD program. Early in the project, a stakeholder consultation was carried out with Road Authorities and operators across Europe that use these technologies in operation, or in trials, in order to identify:

- The approach to traffic management and incident management, and the role of incident detection.
- The relevance, situational and operational conditions for various types of incidents.
- Operational issues
- Performance of the technology or system
- Existing practices and examples of best practice.

The consultation consisted of two parts:

- A web questionnaire on experiences with current incident detection systems [5].
- A short personal interview with stakeholder experts (either by phone or in person) on the results of the questionnaire and their vision for the needs of future systems

Based on the priorities from the stakeholders, a final selection of incident types was made that will be addressed in the remainder of this project (see section 3).

2.1 Stakeholder consultations and questionnaire results

A number of road authorities were contacted to fill in the web questionnaire [5]. Responses were received from 6 countries. The combined results are presented in the following subsections.

2.1.1 Individual priorities

Stakeholders were asked to indicate their first, second and third priority of incident types. A summary of the response is given in Figure 1.

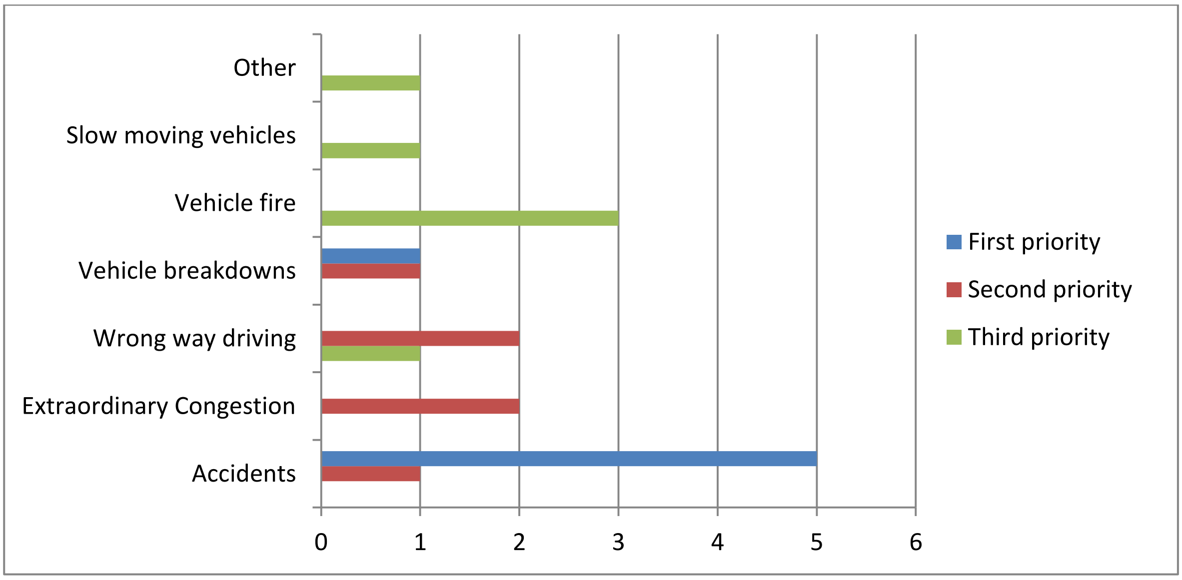


Figure 1: Individual priorities for types of incidents

To make a final order for prioritization, points were awarded for the different levels of priority. The highest priority receives 3 points, second priority 2 points and third priority receives 1 point. The scores were then summed up for the individual incident types. The results are illustrated in Figure 2.

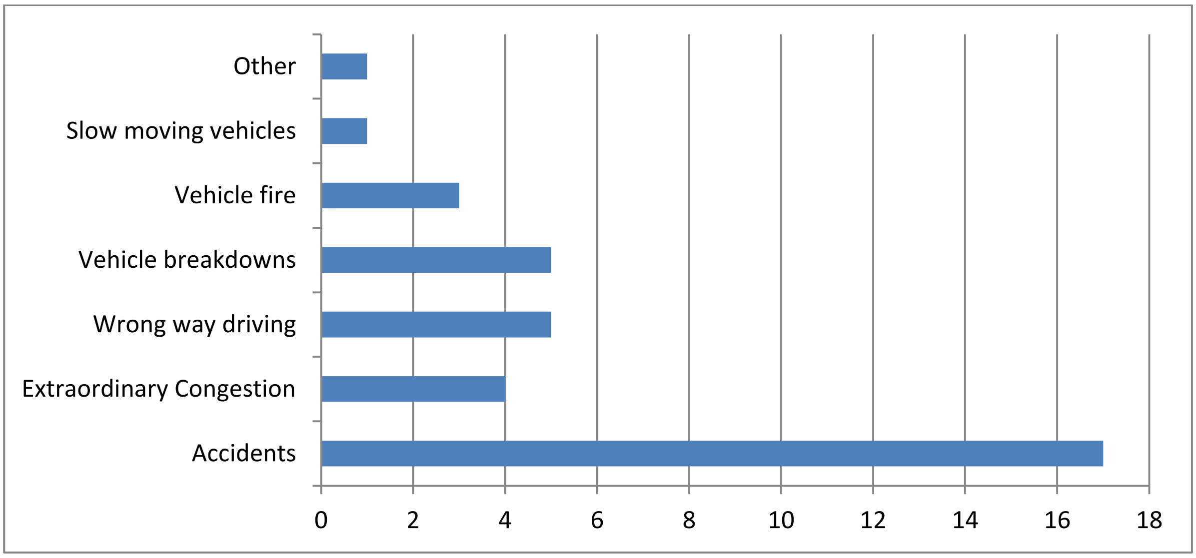


Figure 2: Overall weighted priorities for types of incidents

More types of incidents were included in the questionnaire, but were not prioritized by the stakeholders and are not included in Figure 1 and Figure 2.

2.1.2 Locations and vehicle classes

An important criterion for the stakeholders to assign priorities is the local infrastructure situation. The presence of a hard shoulder or refuge area is important information as vehicles involved in an accident, or broken down vehicles, can seek refuge and significantly reduce the reduction of road capacity and the risk on secondary incidents.

Also the classification of the vehicle(s) that are stranded or involved in the accident is important. When heavy good vehicles are involved in an incident, the severity of the incident is usually much higher.

These factors are not used to differentiate the priorities in Figure 1 and Figure 2, as they could apply to most incident types. However, these factors will be addressed specifically in this project.

2.1.3 Impact of incidents on safety and traffic flow

To obtain a better insight into why the experts consider the named incidents important they were asked to give their views on how heavily these incidents influence safety and traffic flow.

Here again a weighting was made to be able to make a distinction. In this case a high impact was assigned three points, medium priority two points and low priority one point. Again the points were summed per incident class. The results are illustrated in Figure 3. Stakeholders were asked to score the impact for all types of incidents in the questionnaire, also those they did not prioritise in Figure 1 and Figure 2.

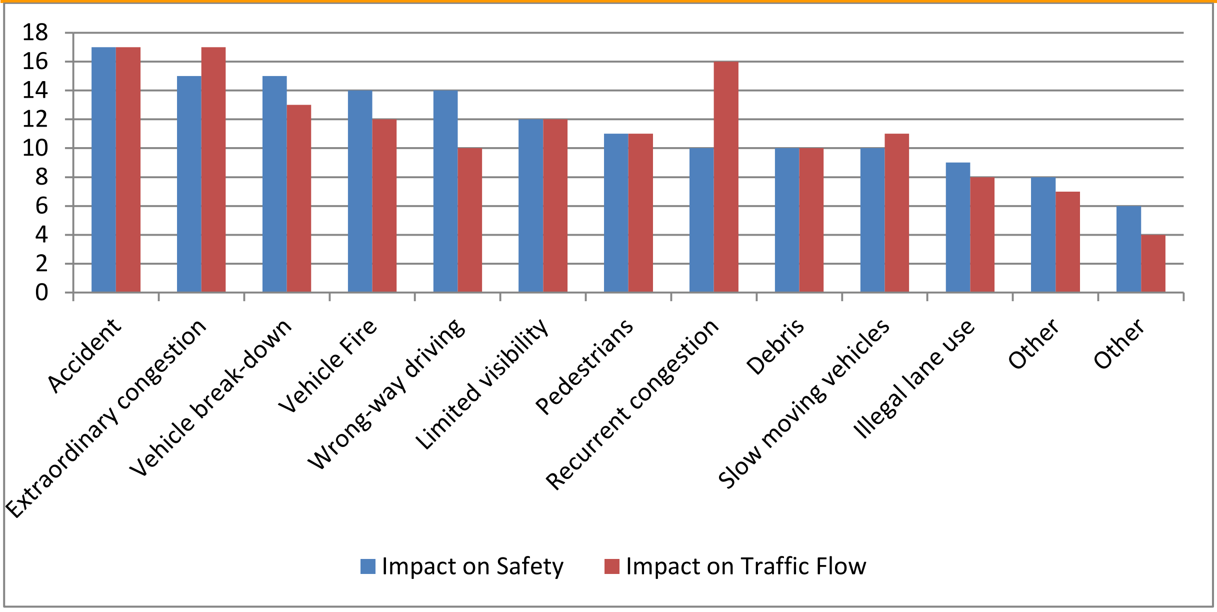


Figure 3: Overall weighted impact on safety and traffic flow

2.1.4 Other incidents provided by stakeholders

Several questionnaire responses also provided incident types that stakeholders considered important in addition to the types that were included in the questionnaire. The named incidents are:

- Fast moving vehicles, referring to cars that go much faster than average speed of the traffic flow.
  In the case that there are only two lanes on a highway and there are a lot of trucks on the highway then merging is often hard. Also those drivers usually have an aggressive style of driving (lighting, using the horn, driving close to the car in front of them).
- Degraded road surface conditions, like wet surface, ice and snow.

2.1.5 Discussion of overall priorities

Considering the individual and weighed priorities of the stakeholders that participated in the questionnaire, it is obvious that accidents are highly distinctive from the other incident types. Hence this was selected as the number one priority.

For the second and third priorities the decision is less clear. Vehicle breakdowns and wrong-way driving attain the next highest 'priority score', although the scores are small compared to accidents. Extraordinary congestion and vehicle fire also have similar scores relative to accidents.

Considering the data provided by the stakeholders in Section 2.1.3 it can be seen that the top three incident types for both 'impact on safety' and 'impact on traffic flow' are: accidents, extraordinary congestion and vehicle breakdown. It was therefore decided that these three incident types would be chosen as the three priorities for RAIDER. Vehicle fire will be considered as a subset of vehicle breakdown.

Wrong way driving is given equal priority as vehicle breakdowns. The impact on safety and flow, however, is scored lower than the top three incidents. It needs to be discussed how the interpretation of wrong way driving by the stakeholders matches (e.g. motorway or arterial roads) and is in focus of this project. For the time being, we only focus on the top three.

2.2 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.

Incident Type	Number of incidents (%ge 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*

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
- 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

These findings support the questionnaire responses that identify the both breakdowns and collisions as priority incident types. Additionally, the importance of vehicle fire incidents (although infrequent in occurrence) is reiterated. Vehicle fire incidents are to be considered specifically as a subset of breakdowns.

3 Incident types and their characteristics

Three types of incidents have been prioritised by the stakeholders in the previous section: accidents, extraordinary congestion, and vehicle breakdowns. This section describes the types of incidents in more detail, as well as the user needs and requirements expressed by stakeholders. Operational issues, expressed by stakeholders, are included with the discussion of detection systems in section 5.

Accidents and broken down vehicles often cause extraordinary congestion. Following this logical order, extraordinary congestion is discussed last in this section.

The following general user needs and requirements can be made that apply to incident detection in general.

- In addition to incident detection, there should also be a method to warn drivers for example via dynamic signs above or beside the road or with a warning on an in-vehicle device. Without the ability to transmit information to drivers, a detection system for the congestion is worthless.
- Heavy goods vehicles have much more impact upon traffic throughput and safety than passenger vehicles when they break down. A heavy goods vehicle cannot be pushed to a hard shoulder or refuge area and blocks a lane completely. It also requires much more time and equipment to recover. Hence it is important to detect the class of a broken down vehicle to assess the impact on traffic and safety.

3.1 Accidents

3.1.1 Definition

A traffic accident in road transport is defined 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.

3.1.2 User needs and requirements

The number of traffic accidents in the EU has continually decreased since the year 2000; however, the self-imposed targets for 2010 were not reached. In Europe around 30,000 people die in road accidents every year [6]. As a result, around 200 billion Euros are lost to the European economy. Therefore, it is a growing political interest in a lot of European countries to reduce fatalities in road transport (e.g. Vision Zero [7]).

This objective can be achieved by:

- Reducing the accident risk and mitigating effects of erroneous driving (pre-crash)
- Passive safety systems of vehicles and road restraint systems mitigating the collision impact (crash)
- Effective emergency measures and ambulance operations in case of an accident (post-crash)

The latter is the main driver for effective incident and accident detection systems by road operators. However, it is noted that accident detection is also contributing to accident risk mitigation by avoiding excessive congestion caused by accidents through strategic traffic management measures. Although another interest of road operators is the secondary effect in terms of unexpected congestion (handled in section 3.3), the main aspect of the accident ‘incident type’ is safety. Effective detection allows the road operator to support emergency actions and reduce the time for emergency vehicles to reach the accident location and casualties. Therefore, even on very low volume roads an immediate detection of such incidents is aimed for.

On high volume roads (i.e. trunk roads and motorways) the identification of accidents triggers other traffic management actions (lane closure, speed limitations on variable message signs, overtake restriction, etc.). 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. [8], paragraph 7.7 “Road fatalities by type of road in EU selected countries – 2006”). Therefore, specific accident detection mechanisms for low volumes, secondary and rural roads are required with very low costs (per network km monitored).

Most of the experiences of accident detection are gained from and implemented within tunnel safety systems. Especially since the dramatic fire disasters in European tunnels (e.g. Mont Blanc Tunnel) the requirements for tunnel safety and accident detection within tunnels are rapidly increasing. Immediate incident detection for accidents (i.e. below 1 min) is required and is followed by immediate actions to ensure safety. Tunnel safety is not only relevant on the motorway network; even on other roads (with tunnels) such systems are in place and monitored either by a local operator or within the centrally organised road control centre.

An important requirement is the need to assess the severity of the accidents in terms of personal injuries or casualties, and the location and class of the vehicles involved. A traffic operator usually receives the first alarm, and needs to make the first assessment of the accident and the required incident management response. Commonly, video cameras are required for the first visual assessment. Detection of personal injuries or casualties is not addressed in this project. Detection of the location and class of vehicles are similar to vehicle break down incidents and are further discussed in section 3.2.2.

There should also be a method to warn drivers for example via dynamic signs above or beside the road or with a warning on an in-vehicle device. Without the ability to transmit information to drivers, a detection system for the congestion is worthless.

3.1.3 What means are currently used for detection?

The state of the art in traffic accident detection on the motorway network is a two-way approach. The technology with an immediate detection capability of accidents is typically a video based system (VIPS/VIDS). These systems are standard equipment for tunnel safety (in many European countries). The complementary approach would be to use traffic flow based sensors to identify extraordinary congestions and assume the causation (see also section 3.3).

The means for accident detection depend on the road class. While on the motorway and trunk road network technical detection mechanisms are in place, on the secondary and rural network no or only rudimentary mechanisms are known. From an overall accident detection point of view this is less than ideal, as most of the accidents (especial fatal and severe accidents) occur on rural and secondary roads [8]. On the “main road network” the systems in use for traffic accident detection are mainly video based systems (VIPS/VIDS). These technical solutions serve the purpose to accurately identify accidents and deliver a visual control picture to the operator for verification of the accident and assess the severity.

Tunnel safety seems to be a primary concern for road operators and the investments for accident detection systems within tunnels are notable. The resources needed for tunnel monitoring are comparable to the resources used in traffic management (apart from tunnels). However, the overall costs are not exaggerated as the number of tunnel-kilometres for monitoring is limited.

The complementary approach is the use of traffic flow based sensors (i.e. inductive loops, radar, and tolling based sensor systems) to identify extraordinary congestions and assume the causation. However, this approach has some disadvantages. In dense traffic, extraordinary congestion will build up due to the accident, but the time to identification of the accident may be significantly longer compared to direct detection approaches. On the other hand, when traffic demand is much lower than the road capacity, traffic accident identification will be poor because extraordinary congestion may not occur and anomalies in lane occupancy may not be detected at all.

Another way to identify accidents on the network is through non-technical solutions commonly used on European roads; the information about accident location (and additional information) is given by other road users to the road operator and the media (mostly radio broadcast).

3.2 Vehicle break-down

3.2.1 Definition

A vehicle break-down incident is defined 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 this project. Many causes of vehicle failures can be considered, such as mechanical failure or fire. Other causes like health issues of a driver or passenger will also result in vehicle stops.

3.2.2 User needs and requirements

In consideration of this incident type and the appropriate response undertaken by road operators, it has become clear that there are distinct subsets of vehicle break-downs that require a variety of responses with different priorities and therefore different user needs and requirements for detection.

Although stakeholder consultation highlighted the high importance with which road operators view vehicle break-downs in general, the specific questionnaire responses clearly identified a clear and consistent concern with break-downs on locations without a hard shoulder or refuge area, such as on extra lane, in tunnels and on bridges.

Specifically, the location of the break-down (and critically the location of the abandoned vehicle) is of fundamental importance. If the vehicle has broken down (and is completely immobilized) within a running lane of the live carriageway, this will have an immediate and significant impact on both safety and congestion. In contrast if the vehicle has broken down and/or is recovered to a safer refuge area (such as a hard shoulder, verge or specific break-down refuge area), the impact on safety and congestion is minimized and/or deferred.

The local situation may change regularly, for example when a hard shoulder is used as an extra running lane, or occasionally for example during road works. In these situations, there is typically no safe refuge. Hence, the severity of incidents and the requirements to incident detection varies with the situation.

Furthermore, any broken down vehicle will require recovery. Incidents that involve broken down vehicles immobilized in a running lane of the live carriageway will have increased levels of congestion which will impact the deployment and delay the arrival of any required incident response unit. This issue is compounded if the incident location is on a carriageway without a hard shoulder.

Additionally, there are added complications with tunnel/bridge locations whereby abandoned road users cannot easily retreat to a safe environment (a distance away from live traffic) and are potentially trapped within a confined space.

The following division can be made on the location:

Vehicle break-down in “special” locations where safe refuge for people and/or vehicles is not provided (such as areas of hard-shoulder running, tunnels and bridges)

- Strong case for specific, targeted and automated incident detection
- High rate of detection with significant confidence and easy opportunity for incident validation
- Timely (immediate) detection such that response can be deployed as early as possible (as incident related congestion will quickly build and significantly impact the incident response time)
- Specific need to monitor congestion

Vehicle break-down in live lane of carriageway

- Strong case for specific, targeted and automated incident detection
- Timely (immediate) detection such that response can be deployed as early as possible (as incident related congestion will quickly build and significantly impact the incident response time)
- Specific need to monitor congestion

Vehicle break-down in non-live lane/recovered to safe refuge

- Incident response/vehicle recovery will be deployed upon incident identification or notification by third party
- It is generally sufficient to monitor status/response and manage any resulting congestion
- The case for direct incident detection is tenuous

3.2.3 What means are currently used for detection?

Broken down vehicles or similar incidents of individual vehicles can be deduced from existing inductive loop detectors. A vehicle that broke down on a live running lane forces other vehicles to find a way around it via other lanes or the hard shoulder. In dense traffic, this will slow down other traffic and ultimately cause a traffic jam and congestion. The congestion can be detected initially by a strong reduction of the intensity on the downstream loop. When the congestion passes the upstream loop is strong reduction in speed can be detected. Depending on traffic density and loop spacing, it may take up to several minutes before the incident can be detected. In low volume traffic, congestion will not occur and the incident may not be detected from the loop data at all. In tunnels, the loop spacing may be reduced significantly to increase the detection probability and reduce detection time of stationary vehicles. In these configurations, the loop detection system may also be used to detect slow traffic. This indirect approach to detecting incidents will be covered in section 3.3 though. Here we address direct detection of broken down vehicles.

Video Image Processing systems are generically the technology chosen for direct detection of vehicle break-downs. Commercial VIPS or VIDS detect vehicles when they are stationary for a few seconds. Recent developments and trials in video image processing show that this technology could also be used to detect vehicles slowing down to stand still or lane changing manoeuvres towards the hard shoulder or refuge area. However, this functionality is not commonly available in existing commercial systems.

Another important reason for using video camera systems is that it enables the operator to visually assess the incident and severity in terms of vehicle types, potential injuries and dangerous goods and collect vital information for further incident management.

Recent developments and trials have focused on the potential for use of other types of systems for detection of vehicle break-downs. Described in subsequent sections, these have included individual vehicle tracking systems based upon inductive loops and dynamic scanning radar based technologies. Of particular note, the scanning radar system has recently been deployed (as a trial) in a live/operational environment within the Hindhead Tunnel on the A3 in Surrey, England.

3.3 Extraordinary congestion

3.3.1 Definition

Extraordinary congestion is the congestion caused by extraordinary events like traffic accidents, broken down vehicles, vehicle fires, wrong-way-driving, road works, or weather events. An event is called extraordinary because the occurrence of the event cannot be, or has not been, predicted in time and location. This distinguishes it from recurrent congestion due to bottlenecks in the road network, capacity limitations during rush hours, or major public events.

The previous subsections discussed the early detection of some types of incidents that can cause extraordinary congestion. When considering the detection of extraordinary congestion, then obviously the initial cause has not been detected or the congestion effects could not have been prevented, and the incident has already progressed to the phase of a detectable congestion.

3.3.2 User needs and requirements

In terms of the stakeholder consultation, the impact on the traffic flow is the most important aspect for extraordinary congestion, although the impact on safety is in reality just as important.

Extraordinary congestion is major cause for unreliable journey times on the road network. For traffic management, it is important to know the increase in travel time. That information can be used to give route advice to road users or, in cases of extreme increases in travel time, to reroute road users.

For traffic safety the detection of the tail of the congestion is important in order to warn upstream traffic and reduce the risk on secondary incidents. A traffic jam usually grows with about 5-6 m/s and the jam tail travels the distance between two loops and message signs at 500m 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 metres with a detection time of less than half a minute.

3.3.3 What means are currently used for detection?

In the current situation congestion is commonly detected with inductive loops. Loops that are installed with an intermediate distance of several hundred metres 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.

Other types of sensors like radar or video are also used occasionally. The outputs of these sensors for this application are similar to inductive loops; flow and speed and mostly aggregated to one minute values.

Congestion is also 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 scanners 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.

4 Performance criteria for incident detection systems

The user needs and requirements from section 3 consist of situational criteria and performance criteria. The priorities for the incident types are primarily determined by the impact of the incidents on traffic and safety in critical situations. These critical situations are determined for example by the local infrastructure, whether a hard shoulder or refuge lane is available, and the vehicle class. These criteria define the conditions under which the performance of incident detection systems is most critical.

The performance of an incident detection system ultimately determines the quality of the data provided for traffic control and incident management. Criteria on the performance of incident detection systems are more difficult to quantify, even for the prioritized incidents in the most critical situations. Several reasons can be observed. A few frameworks have been developed to objectively and quantitatively evaluate the performance, e.g. in [9], [10]. Implementation in field tests, however, requires significant work and only a few are reported publicly, e.g. [11] [12]. More importantly, the performance strongly depends with the deterioration and maintenance on the systems, and the performance perceived in operational use may be significantly less than evaluated in tests or initially specified.

In this section, the performance criteria will be introduced that will be used to compare technologies in the next phase. Operational experience with performance will be presented in section 5 as far as we obtained so far.

In [1] it is recommended to further analyse the incident management process and define timelines for the consecutive steps including the detection of the incident. In such an analysis, requirements on the acceptable or maximum time for detection can be imposed based on the timing for organisation of the response actions. Similarly, the data necessary for response defines the information that needs to be collected about the situation and the accuracy of the incident location.

4.1 Situational parameters

The situation describes when and where an incident occurs. The following situational parameters are identified (extended from [9]):

1. Operating traffic conditions (e.g., heavy, medium, light, at capacity, and well below capacity)
2. Geometric factors (e.g., grade, lane drops, and ramps)
3. Environmental factors (e.g., dry, wet, snow, ice, and fog)
4. Incident duration
5. Incident severity (injuries and casualties, amount of damage, impact on traffic flow and safety)
6. Detector spacing
7. Incident location (relative to detector station)
8. Number and type of vehicles involved in the incident
9. Heterogeneity of vehicle fleet.

Ideally, the incident detection system and traffic monitoring system should provide this situational information to prioritize incidents for incident management. It is observed in [9] that “these factors are so complex that they cannot all be readily accounted for in a single detection algorithm, especially in an arterial environment. None of the existing algorithms has been tailored to consider all of these factors. Thus, they cannot be expected to succeed in all traffic”. Nevertheless, the variations in situations may have a significant effect on detection performance.

4.2 Performance measures of Incident Detection Systems

The performance of incident detection system can be evaluated objectively by the measures defined in literature and field test report defined, e.g. [9] [10] [13]. These references also list quantitative data from performance evaluations of sensors and detection algorithms.

The performance measures assume that a ground truth is established of incidents that actually occurred so that detections can be objectively classified as correct or incorrect. Generally, average or minimum and maximum values are determined in field tests to express the performance.

Detection Rate (DR)

Detection rate is defined as a ratio or percentage of the number of detected incidents to the total number of actual incidents during a given time period.

Time To Detect (TTD) or Detection Time (DT)

Time to detect is defined as the time from when the incident occurs until it is detected. TTD is usually expressed in minutes or seconds and expresses whether an incident can be detected in a timely fashion for incident management. Generally, the mean time to detect (MTTD) is determined.

False Alarm Rate (FAR)

False alarms are so-called false positives, and are counted when a detection system triggers an incident alarm but no actual incident has occurred. False alarm rate has different definitions for different applications.

- FAR can be defined as a percentage of false detection with respect to the total number of detections. Detections can be classified as false by verification of the detections of the system. Determination of the total number of detections is more difficult:

  FAR1. Total number of real incidents
  FAR2. Total number of detected incidents
  FAR3. Total number of correctly detected incidents

  The total number of real incidents requires a ground truth and is the most objective criterion. In practice, when different detection systems are compared, this number can be approximated by taking all detections made by any one system (FAR2), but this will also include false positives. Verification of all detections allows to filter out the false positives (FAR3).

- FAR can also be defined as the number of false detections per time or distance measure.

  FAR4. False alarms per unit of time, e.g per hour
  FAR5. False alarms per unit of time and distance, e.g. per hour per km.

  This measure expresses the operators' workload.

Location accuracy

The accuracy of the detected incident location is defined as the distance between the real and detected incident location.

4.3 System configuration and optimisation

Incident detection system performance can be optimised to best match the user needs and requirements. As Figure 4 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.

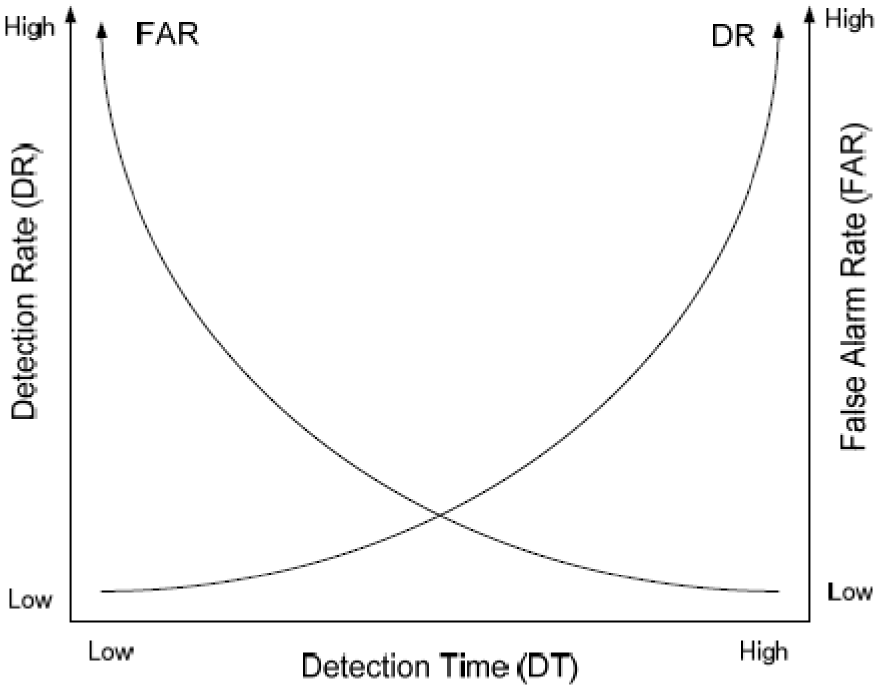


Figure 4: Incident detectiion performance measure relationship ([13] Figure 7)

Similarly, 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).

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 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 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 (Figure 5). 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.

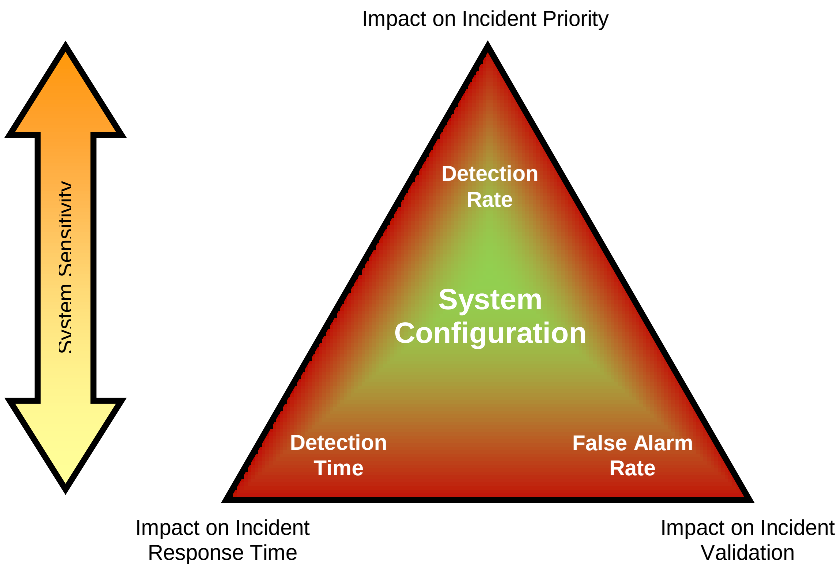


Figure 5: System configuration trade off

Defining performance requirements that are both appropriate and achievable requires consideration of which factors are fundamental and which factors can be compromised to ensure timely/efficient response. Table 1 gives a qualitative overview of the performance requirements for the prioritised incident types.

Table 1: System configuration requirements per incident type

Incident Type	Severity	Response	System Configuration: Detection Rate	System Configuration: Detection Time	System Configuration: False Alarm Rate
Accident	Damage Only	• Recover vehicle • Monitor congestion • Traffic management	✗	●	✓
Accident	Minor	• Medical services as required • Recover vehicle • Monitor congestion • Traffic management	✓	●	✓
Accident	Fatal / Major	• Immediate emergency response (fire, ambulance, police as required) • Medical services as required • Recover vehicle • Monitor congestion • Traffic management	✓	✓	✗ 1
Extraordinary Congestion	n/a	• Monitor congestion • Traffic management	●	●	✓
Breakdown	Vehicle in safe refuge area	• Recover vehicle • Monitor congestion • Traffic management	✓	✗	✓
Breakdown	Vehicle in live lane	• Retrieve vehicle to safe location • Recover vehicle • Monitor congestion • Traffic management	✓	✓	✗ 1
Breakdown	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 significant 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

5 Detection systems – a state of the art

The state of the art of new and near-future technologies for incident detection is reviewed in this section. The review has a focus on the recent performance and improvements of these technologies. This review will serve the further assessment of operational experiences with existing systems and the feasibility of adopting or integrating new technologies in the next project phase. Hence the review in this phase is a quick scan of the potential of technologies.

The state of the art of innovations in existing road side systems like inductive loops also had to be reviewed in order to assess the potential improvements and for gap analysis in the next project phase.

In 2005 [9] an extensive overview was made of sensor technologies and detection algorithms for automatic incident detection and probe systems. Incident detection is primarily focussing on congestion and indirect detection of incidents, comparable to the extraordinary congestion type defined in section 3.3. The authors follow a similar approach to evaluating detection performance and report some performance figures that are indicative of the technologies. Some results will be quoted below per sensor technology. The authors also compare road side incident detection systems to some in-vehicle systems and nomadic devices. The conclusion in 2005 is that the performance of automatic incident detection is still unsatisfactory, e.g. that the alarm rate is still too high for operational use, and the authors suggest to also rely on driver-initiated incident reports by cell phone calls.

Overviews of existing incident detection algorithms and their performance can be found in [10] and [13]. Some selected algorithms will be discussed below per sensor technology.

5.1 Inductive Loop

5.1.1 Background to Technology

Historically, inductive loop technology has provided the de facto system for traffic data collection and 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) Figure 6.

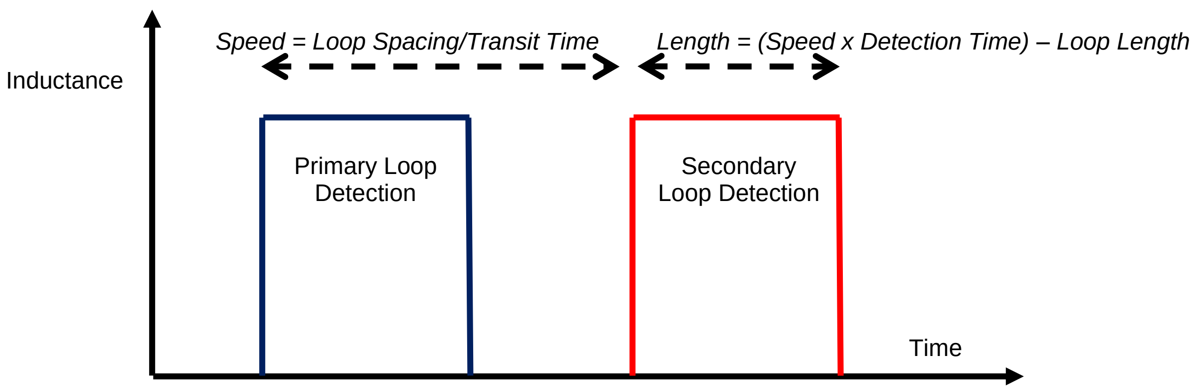


Figure 6: Double inductive loops for measuring speed, length and headway

Traditionally, an inductive loop detector (ILD) acts as a simple Boolean logic type presence detector (presence: yes/no) that is performed cyclically. Therefore, a key consideration to implementation of an inductive loop site is the sensitivity of the detector. The sensitivity of an inductive loop detector is represented within the induction pattern (relative change in inductance – dL/L) that is observed as vehicles of different types/sizes pass over the loop array.

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

As illustrated below (Figure 7), if overlooked (and not compensated for) variation in loop sensitivity will influence the interpolation between the analogue inductance pattern and the simplified presence measurement.

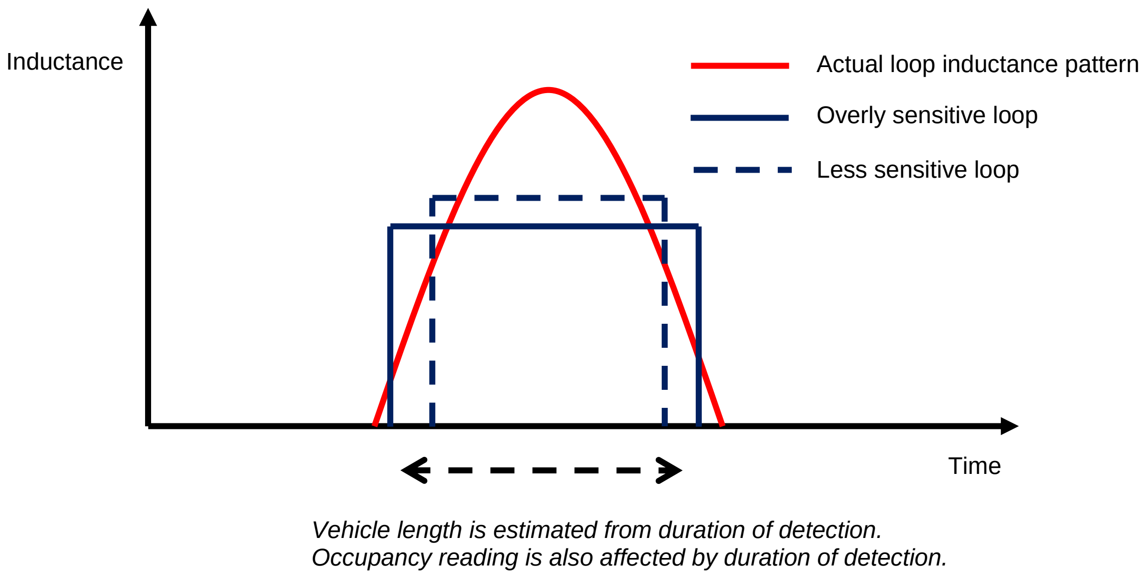


Figure 7: Variation in loop sensitivity

To ensure confidence in data used for incident detection (such as occupancy); the sensitivity of an inductive loop is configured during installation.

5.1.2 Current Operational Experience

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.

The experience from the motorway operators of indirect traffic accident detection is quite extensive. Accidents have on the most part been the prime objective of incident detection (specifically for road safety and traffic flow). With the implementation of variable message signs and the possibilities to control the traffic at accident locations, the requirements for fast and exact identification of accidents grew. Therefore, the experience with different technologies and sensors for accident detection goes back to early 1990s.

Road Authorities and operators have decades of experience with traffic and incident management systems using inductive loops and variable message signs, such as MIDAS in the UK and MTM in the Netherlands.

United Kingdom (Highways Agency)

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.

Regularly spaced inductive loops monitor network conditions, congestion is detected and advice provided to the road user (such as "Congestion Ahead – Slow Down" on VMS or mandatory variable speed limits within the Managed Motorways initiative) in an automated manner.

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.

Within the MIDAS system; there are two main algorithms with very distinct purposes.

Speed/Flow 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. Generally the High Occupancy Algorithm can be triggered in two ways:

- Instantaneous Occupancy – when a constant (100% occupancy) detect exceed pre-defined thresholds. This threshold represents an inductive loop detecting constant presence for a period of time (for example 4 seconds) that is greater than that can be explained by a long passing vehicle (even one travelling at relatively low speeds).
- Smoothed Occupancy – when smoothed occupancy exceeds pre-defined thresholds. This threshold represents a floating average approach to measurement of occupancy. Each period of time that presence is detected, the floating average increases; conversely each period of time that no presence is detected, the floating average decreases. As congestion builds, the floating average increases until a predefined threshold (that represents 'congestion') is exceeded and an alert is raised.

The HIOCC algorithm, described in further detail in [14], is summarized as follows.

Smoothed occupancy is calculated as perturbation of current occupancy and the previously calculated occupancy:

$$\{\text{Smoothed Occupancy}\}_n = P \times \{\text{Instantaneous Occupancy}\}_{n} + (1 - P) \times \{\text{Smoothed Occupancy}\}_{n-1}$$

Where P = 1/64 is a typical value

The Smoothed Occupancy is continually monitored against a pre-defined threshold. In the event of smoothed occupancy exceeding this threshold the algorithm functions in the following manner:

i. Smoothed occupancy is artificially raised (instantaneous) to a defined level (nominally 90%) – to avoid periods of on/off alert fluctuations
ii. Smoothed occupancy calculation is suspended for a defined period of time (nominally 8 seconds) – to ensure continuity in stop/go conditions

iii. Alarm is terminated when smoothed occupancy recalculation is reinstated and returns to the (smoothed occupancy) value that would have been measured should the (i) artificial raising and (ii) suspension of recalculation not have occurred.

A recent enhancement to the original HIOCC algorithm, the HIOCC2 algorithm, is currently being implemented in MIDAS. The process defined above is retained and coupled 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 [15].

This approach provides a system that detects the onset of extraordinary/incident related congestion with a significant level of confidence to deliver automated response in a timely manner.

Inductive loops have proven a great success for this application and have delivered the expectations of the Highways Agency for incident detection in an automated manner to provide pre-emptive response that can often negate potential flow breakdown and congestion.

The Netherlands (Rijkswaterstaat)

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 [3]-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.

AID (Automatic Incident Detection)

The AID is activated at a speed underflow of 35 km/h. At that moment a speed limit is set on the variable message signs at the location of the loop and two message signs stream upwards (at approximately 500 and 1000 meters from the loop). The speed limit is 50 km/h at the loop where the speed underflow is detected, 50 km/h with blinking lights the sign stream upwards and 70 km/h with blinking lights the next sign stream upwards.

Travel time and congestion

The Monica data is used by the MoniBas system, that calculates travel time and the length of congestion. The increase in travel time is displayed on variable message signs at important points in the network. The data is also provided to traffic information providers.

Tunnels

In the Netherlands tunnels are instrumented with loops every 75-100 metres. Two algorithms are used to detect irregularities in the traffic flow like slow moving and stationary vehicles. Steep tunnels results in false alarms due to heavy trucks that cannot maintain or accelerate to speeds above the alarm threshold. Also tunnels in urban environment generate a lot of false alarms due to congestion caused by traffic lights.

5.1.3 Recent and Future Developments

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.

As discussed previously within this report, the conventional approach to inductive loop detectors is based upon discrete detection of presence (yes/no) of a vehicle. 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.

As illustrated previously, an overly sensitive loop will detect presence over a longer period of time, and will hence estimate vehicle lengths as being longer than they actually are whilst over estimating loop occupancy. In contrast a less sensitive loop will detect presence over a shorter period of time and will hence estimate vehicle lengths as shorter and under estimate loop occupancy.

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 (Figure 8). This offers two significant benefits.

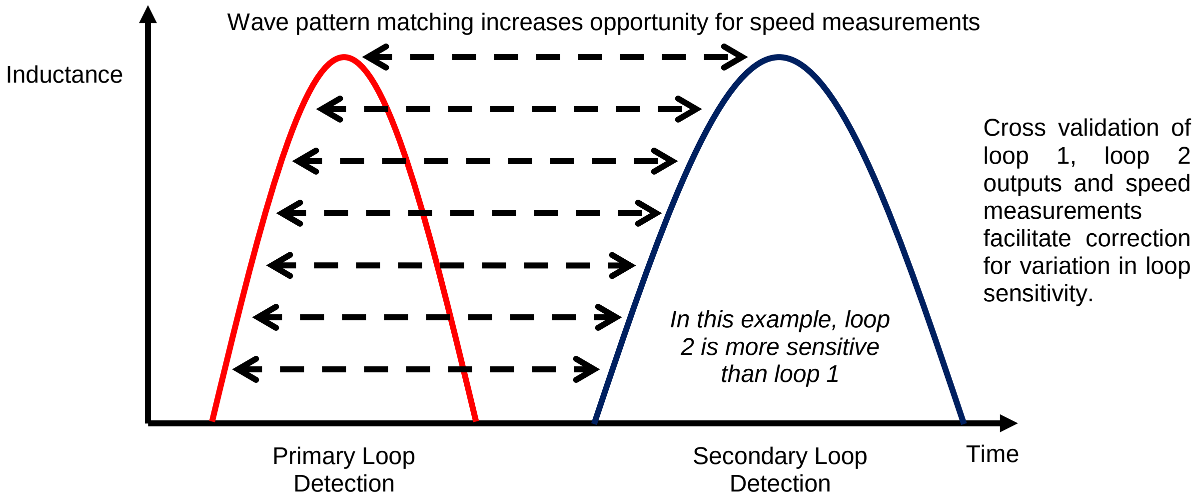


Figure 8: Inductance pattern of loops

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, and troughs). 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. 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

In the Netherlands experiments have been done with an incident detection algorithm based on inductive loops [16]. The algorithm was based on a strong reduction in traffic flow downstream incidents and a decrease in speed upstream of incidents. Evaluation in the traffic centre showed that the algorithm has too many false alarms and too long detection time although there was a relative high density of inductive loops.

5.2 Radar

5.2.1 Background to Technology

Radar traffic data classifiers are a proven and commonly used technology for temporary traffic data collection sites. There are significant advantages over inductive loop technology with ease and cost of installation, configuration and maintenance.

There are, traditionally, two configurations of Radar sites as traffic data collection sites:

- Side-fired Radar sites are targeted transversely (across) the live carriageway and utilize the distance (depth of field) measurement (from reflection) functionality of Radar such that vehicles in each lane are detected and tracked (across the field of view). Lanes are configured vertically across the field of view, whilst vehicle speeds are estimated by tracking the vehicles horizontally across the field of view
- Longitudinal Radar sites are targeted towards the oncoming vehicle and hence offer enhanced performance, whereby vehicle counts/presence is measured for each lane using the distance (depth of field) measurement, but vehicle speeds can be measured using Doppler shift approaches (to improve accuracy).

The main limitation with Radar systems is because of the issues of obscuration due to the line of sight nature of the technology. Of particular note for side-fired installed systems (if installed in the verge); vehicles, and especially HGVs, passing by the radar site can potentially obscure vehicles in all other lanes. The main impact of this issue is a reduction in accuracy of traffic count/flow statistics and instantaneous occupancy readings of any lanes obscured from direct line of site.

Despite these limitations, it is noted that there has recently been substantial improvements in performance of such systems. An on-road trial of this technology was undertaken by the Highways Agency in 2007. This trial demonstrated that quality of traffic data collected by side-fired IR Radar technology was of sufficient quality and accuracy to be suitable for implementation within the MIDAS Incident Detection System.

5.2.2 Current Operational Experience

United Kingdom (Highways Agency)

Although at the moment, there has been very limited use of Radar technology within live operational environments, use of this technology is fully supported by the Highways Agency. Side-fired IR Radar systems are increasingly being approved by the Highways Agency for installation (in replacement of inductive loops) at MIDAS Incident Detection sites where loop arrays have failed. A major advantage of radar is that it can be installed without road closure.

The Netherlands (Rijkswaterstaat)

At some places loops are replaced by FALCON radars. These radars are placed above the road and have the same functionality of an inductive loop.

5.2.3 Recent and Future Developments

As discussed earlier within this report, the practicability for use of Radar (predominantly Infrared) as a traffic classifier has been clearly demonstrated and use of this technology (generally as a replacement for inductive loop sensors) has become common practice.

Recent developments from other industries have demonstrated how this technology could be implemented for direct detection of incidents.

Already common place 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 [17]. 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.

5.3 Video (VIPS/VIDS)

5.3.1 Background to Technology

Video cameras are widely used to monitor traffic. An important advantage over any other sensor technology is that the video can be displayed in real time to traffic operators to monitor traffic and to verify alarms generated for incidents and to support incident management.

The Video Image Processing Systems (VIPS) can automate the processing of video images to extract traffic information. The early systems used imaging techniques like background subtraction and virtual loops or virtual line analyses. Virtual loops or lines can be defined in the camera view as detection zones. Background subtraction detects any changes relative to the background of the video camera for example due to moving objects. The road surface forms the background of the video. This background changes when a vehicle or pedestrian passes. These systems are used for example to detect the presence of vehicles or pedestrians on a hard shoulder or in a tunnel from which incidents are inferred like stationary or slow moving vehicles, pedestrians on the road, and stationary vehicles due to accidents. From the background, degraded visibility situations can also be detected like smoke and fog.

The systems can also be used to collect basic traffic data, like occupancy and flow, on a virtual detection line or area, to act as an alternative to inductive loops and to detect incidents indirectly.

Unfortunately, many other phenomena can also affect background subtraction, such as changes in lighting due to shadows clouds and position of the sun, darkness and vehicle lights, or tree branches moving in the wind. Many algorithms have been developed to improve the negative effects of these phenomena on traffic and object detection. Nevertheless, detection performance may vary significantly with environmental and situational conditions (section 5.3.2).

Another fundamental issue is occlusion, which video shares with radar and other line-of-sight systems (section 5.2.2). When one object is partially obscured by another, they tend to blur into one detectable object with consequent detection errors. Occlusion increases typically with the density of traffic and camera range. Cameras can be positioned and configured to minimize the occlusion for a specific purpose. There is no single best position though; the optimal positions are different for traffic monitoring by an operator, collecting traffic data, and detecting incidents at particular lanes.

A significant improvement over background subtraction is achieved by feature-based image processing. An object such as a vehicle is detected by the classification of features in a single image. There are many types of image features, and usually an object is classified (detected) by the presence of a large number of neighbouring features. This approach is more robust to partial occlusion and variations in lighting conditions. Another advantage is that objects, and their constituting features, are identified individually and can be tracked over successive video frames. This allows tracking vehicles and pedestrians over time from which motion state parameters can be derived such as speed, direction and headways. From this information, incidents like slow moving vehicles, wrong way driving, and accidents can be derived (e.g. [18], [19], [20]).

5.3.2 Current Operational Experience

Road operators have extensive experience with video monitoring systems along highways and in tunnels. The majority of systems consist of pan-tilt-zoom cameras that are mainly used by traffic operators for visual monitoring of the traffic state and verification of reported incidents. Many operators also have experience with VIPS and VIDS since the early nineties when these products became more widely available. Typical applications are traffic data collection, congestion detection and intersection control. In general, the performance in terms of detection rate and false alarm rates, was not sufficiently good for operational use. An evaluation can be found in [11], albeit in a series of small scale field tests for intersection control. Of particular interest is the significant variation in performance of the different systems. Fundamental issues with video image processing do not seem to be improved significantly in [9].

Several road operators have reported a perceived limitation of performance for Video Image Processing systems that manifests in detection and false alarm rates not meeting expectations. Common causes for the performance issues are either installation flaws or more fundamental issues of image processing. Performance for incident detection will deteriorate with non-optimal camera positioning and calibration, stability of camera mounting, camera and algorithm configuration, or maintenance (clean lenses). Performance may also degrade due to occlusion in dense traffic, lighting and visibility conditions.

Over the last decade, however, new requirements for applications like hard shoulder monitoring and tunnel safety have resulted in new developments and improved performance.

Hard shoulder monitoring

In [21] a small field trial was conducted to evaluate the performance of a commercial video based systems to detect slow moving and stationary vehicles, debris and pedestrians while opening and running a hard shoulder. The reported incident detection rate was 98% over various weather conditions for stopped vehicles; 99% in daylight and 94% during darkness. The false alarm rate of 0.3% was deemed too high for operational use.

The detection rate for pedestrians and debris (a trolley of 0.4m by 1.0m) on the other hand was very poor (9 and 18% resp.) and not suitable.

As another example, during 2007 representatives from TRL visited the control centre for the hard shoulder running section of the A86 (near Paris, France) to observe and understand the status and operations of the video based incident detection system.

The hard shoulder running system consisted of four component parts:

- Fixed CCTV Video Image Processing System installed on the carriageway
- Retractable vehicle restraint system controllable from the control centre
- Variable Message Sign system to advise on status (open/closed) of hard shoulder
- Control centre with CCTV and automated incident monitoring and detection

The system was configured with clear consideration to both the performance requirements of hard shoulder running and effectiveness of the operational environment.

- One monitor of the CCTV wall was reserved to always display the most recent AID alarm; this way it was a quick and easy process for the on-duty operator to identify incidents and dismiss false alarms.
- A second monitor of the CCTV wall was reserved to display a continually scrolling cycle of all cameras in succession of location.
- Remaining monitors could be configured as appropriate by the operator.

This design facilitated effective monitoring of incidents and operation of the hard shoulder running:

- Incident monitoring – would be identified and verified immediately
- Operation of hard shoulder running – the status (clear/obstructed) of the hard shoulder could be confirmed quickly and easily prior to any opening of the hard shoulder. When and only when the hard shoulder was determined to be clear, would the retractable vehicle restraint system be operated, the VMS activated and thus the hard shoulder opened

Incident detection in tunnels

The EC Directive [22], defines the minimum safety requirements for tunnels greater than 500m in length throughout the the Trans-European Road Network. This directive mandates the use of video monitoring systems and automatic incident detection systems (Art. 2.14.1).

This has resulted in further developments of commercial VIDS for tunnel application for incidents like stopped and slow vehicles, pedestrians, traffic jams, wrong way driver, and smoke (e.g. [18] [19] [23]).

5.3.3 Recent and Future Developments

Developments are in two directions. Image processing algorithms for detection are improved to better cope with adverse lighting conditions (e.g. in [24]), for example during nighttime with/without streetlighting and vehicle head lights, and during day time to cope with sun light and shadows.

Another development is the improvement of object tracking to better model vehicle and pedestrian behaviour, and to classify and predict conflicting trajectories. This enables better assessment of the risk of accidents for example by detecting anomalous lane changing behaviour, tail gating and conflicting vehicle trajectories (e.g. [24] [25]).

5.4 ANPR

5.4.1 Background to Technology

Automatic Number Plate Recognition (ANPR) detects and recognises the lincense 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 25-30 images per second and detect the passage of the vehicle in the videostream.

The detection percentage of ANPR varies between less than 70% to maximum 98%. Full 100% is not reachable due to dirty license plates and other effects.
For incident detection one ANPR camera is not suitable. When more 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.

5.4.2 Current Operational Experience

ANPR systems are widely used for tolling systems, trajectory control systems and travel time prediction systems. Algorithms for detection (extraordinary) congestion can be used as described for tolling systems.

5.5 Tolling Systems

5.5.1 Background to Technology

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 in-vehicle units in order to collect data for vehicle detection, identification and classification. 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) [26] 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. In addition, flow and local speed of all vehicles are measured at selected toll gantries [27].

5.5.2 Current Operational Experience

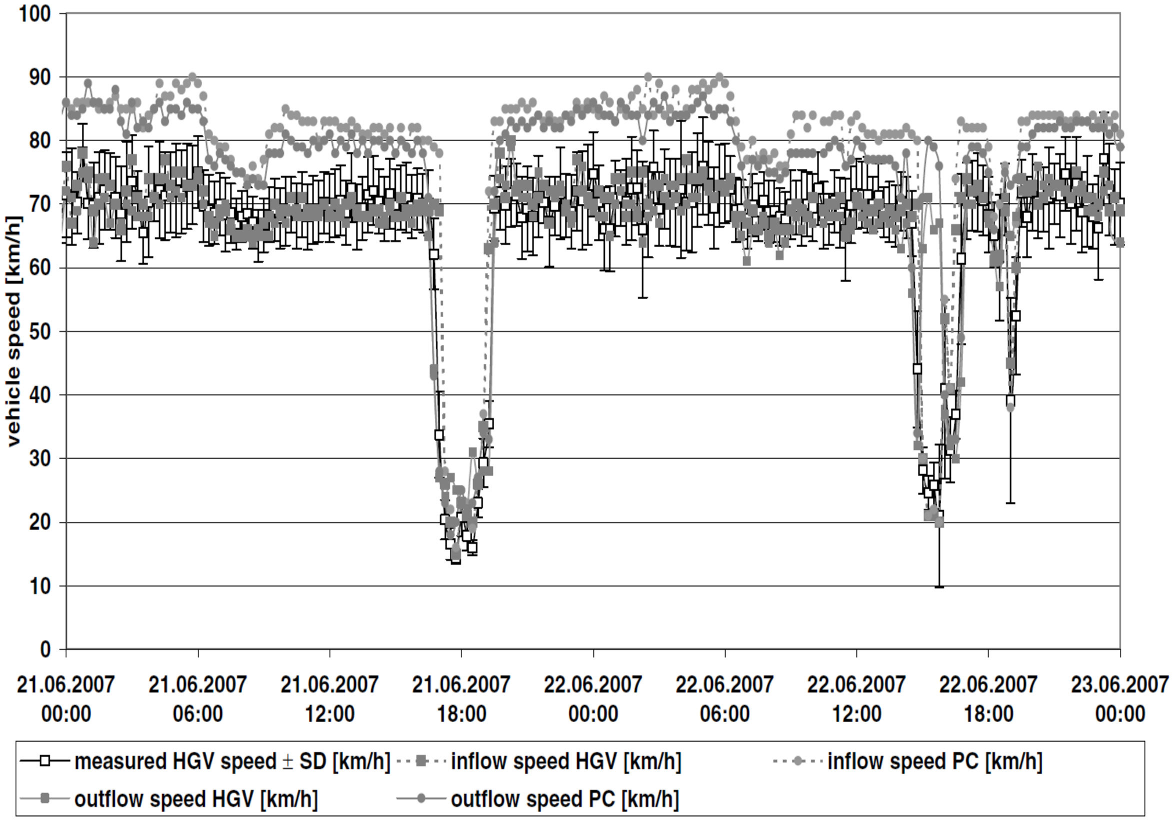
HGV constitute a fraction of total traffic flow between 5% and 30% during a typical working day. The remaining vehicles which are not observed by the ETS system (light goods vehicles, passenger cars (PCs), etc.), constitute the major fraction of traffic with a dominant influence on traffic density and traffic performance. Furthermore, most HGV vehicles (except, e.g., buses) 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 recorded [27].

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.

Figure 9 shows the inflow and outflow speeds of HGVs and PCs, local measurements on the beginning and end of the observed section on the highway A23 and the measured HGV speed from toll data. Velocity values of HGV and of passenger cars 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).

In [9] section 1.4 several other algorithms are described that also use travel time, density, headway and lane switches to detect anomalies in traffic flow as indications of congestion.



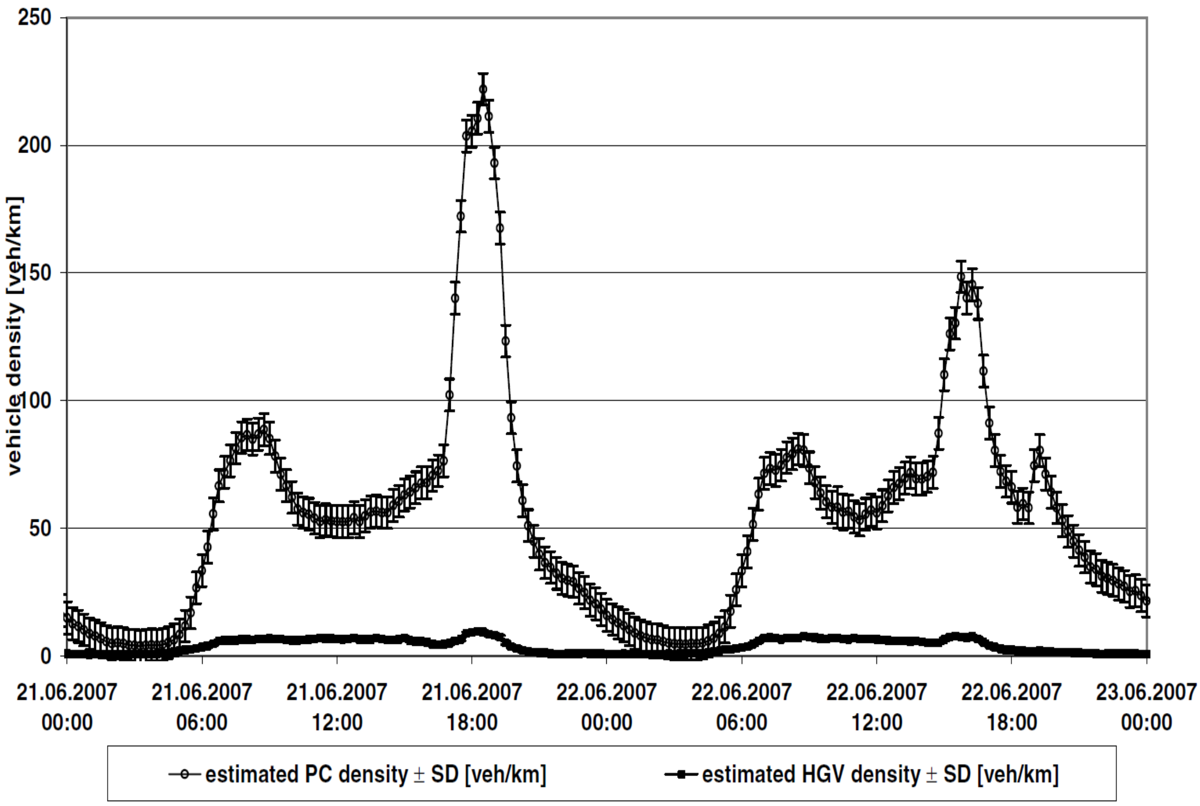


Figure 9: Comparison of measured route speed for HGV and PC (Intraurban motorway A23, two weekdays) from [27].

5.6 E-Call

5.6.1 Background to Technology

E-Call stands for ‘Pan-European in-vehicle emergency call system’ and is most suitably described as a user-instigated or automatic system to provide notification to the nearest Public-Safety Answering Point (PSAP) in case of a vehicle crash. The automatic detection of an accident is based on vehicle sensors or the sensors built into the E-Call device. The in-vehicle sensors can detect (for example) the triggering of an airbag, intense deceleration, vehicle roll-over or a sudden temperature increase. A PSAP, sometimes also called "Public Safety Access Point", is one of several national call centres responsible for answering 112 emergency calls and dispatching police, fire fighting, and ambulance services. E-Call technology has already been in existence for more than 10 years and numerous private emergency call services were initiated in the USA and several other countries. The penetration of those services however is limited at best and does not work in all EU member states.

5.6.2 Current Operational Experience

According to the European Standard EN 15722 (2010), more than 100 million trips to other (EU-15) member states are conducted every year. Whilst approximately 65% of those travelling abroad feel less protected in comparison to being home, most of them do not even know which numbers to call when being involved in a crash or being stranded due to a vehicle break-down.

One of the main reasons the European Commission actively promotes a public pan-European E-Call service are safety benefits due to a higher efficiency in the rescue chain. E-Call operates differently to other in-vehicle signage systems (IVSS) as it does not alter the vehicle collision probability but instead affects the severity of the accident by reducing rescue time. This is known as the ‘Golden Hour Principle’ of accident medicine. One hour after an accident occurred, the death rate of people with heart or respiratory failure or massive bleeding approaches 100%. Hence, rapid reaction of rescue services is crucial to the chance of survival. Figure 10 depicts a typical rescue chain, whereas E-Call aims at minimizing the time components t1 to t6. On the one hand, the time before the arrival of rescue services can be shortened by automated reporting; on the other hand, detailed information about location, vehicle type and propulsion storage type help to optimize incident clearance.

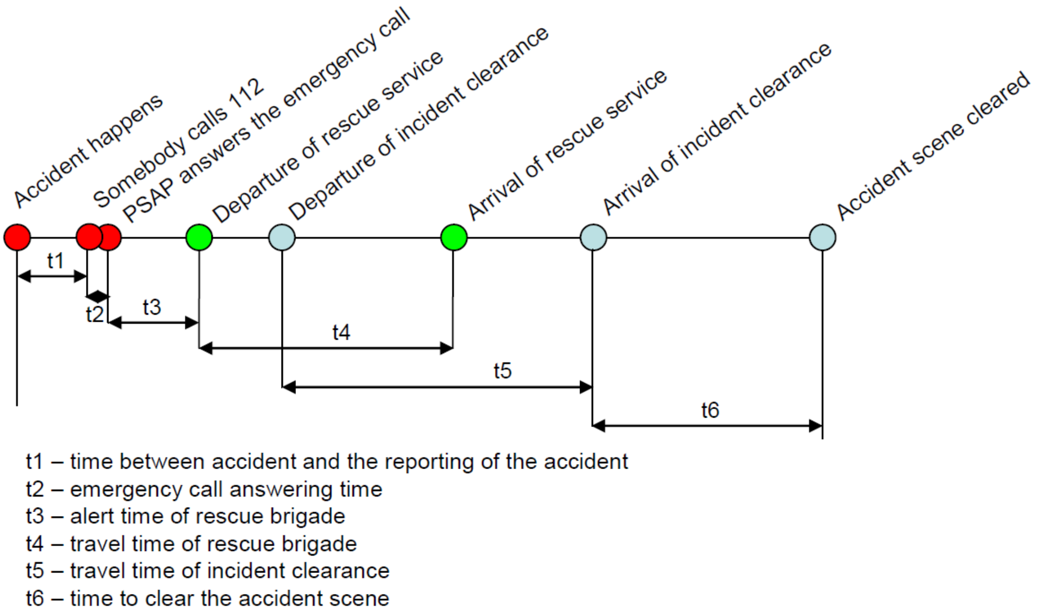


Figure 10: Time components of a rescue chain (EC 2005)

According to the EU-project E-Merge and the eSafety Driving Group, 5-15% of road fatalities could be reduced to severe injuries and 10-15% of severe injuries to slight injuries if E-Call was available in every vehicle (see Table 2).

Table 2: Effects of E-Call on accident severity and congestion time – low and high impact

Effect on accident severity	**Low impact**	**High impact**
Road fatalities changed to severe injuries	5%	15%
Severe injuries changed to slight injuries	10%	15%
Traffic Effect		
Reduction in congestion time	10%	20%

Source: SEiSS, Final report, page 106

The in-vehicle E(mergency)-Call is generated either manually by the vehicle occupants or automatically via activation of in-vehicle sensors after an accident occurred. When activated, the E-call device connects to the nearest PSAP and automatically sends a Minimum Set of Data to the E-Call operator receiving the emergency call. This set includes vehicle identification data (VIN number according to ISO 3779, World Manufacturer Index WMI, Vehicle Type Descriptor VDS, Vehicle Identification Sequence VIS), vehicle propulsion storage type (gasoline, diesel, natural or propane gas, electric energy), time stamp, vehicle location (GPS coordinates) and direction, recent vehicle location, number of passengers and service provider.

One should consider the applicability of the Minimum Set of Data for traffic incident management. The E-Call system covers all roads instead of certain sections and delivers highly accurate location information. In the year 2006, the European Commission, the automobile industry, public authorities and other relevant stakeholders (eSafety initiative) agreed to introduce E-Call as standard equipment in all vehicles entering the European market after September 2010. In 2008, an assessment was carried out of the potential impact of the introduction of E-Call services in Europe [28]. In the „do nothing" scenario the total penetration rate for 2020 is estimated at 6%, in the voluntary approach at 23% and in the mandatory introduction scenario at 42% (see Figure 11). According to the analysis in [28], only the mandatory introduction scenario achieves a cost-benefit greater than 1 by 2030.

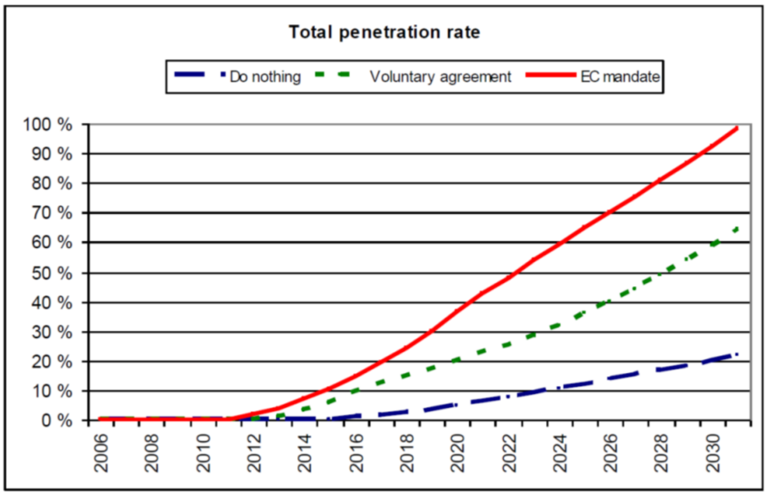


Figure 11: Penetration rates for 2020 and 2030 following three scenarios of E-Call implementation, [28] page 221.

5.6.3 Recent and Future Developments

Of interest to this project is how eCall systems can be combined with in-vehicle systems and into the incident management process.This will be researched in more detail in the next project phase.

5.7 Nomadic Devices

In the context of this project and incident detection, we consider devices nomadic if the devices are mobile and not integrated with systems and sensors in vehicles and have functionality to detect vehicle manouevres, weather and road conditions (section 5.8). Examples of nomadic devices are navigation systems, Bluetooth devices, mobile phones phones, and fleet management tracking systems.

5.7.1 Background to Technology

Although not currently prevalent in their application as a mechanism for incident detection, there is an increasing pool of Nomadic devices that could be harnessed as a mechanism for incident detection. Nomadic devices could provide a suitable mechanism for direct detection of incidents as well as inferred information about network conditions:

- Direct Information – incidents involving equipped vehicles are detected automatically and an alarm raised
- Inferred Information – equipped vehicles act as probe vehicles to capture data relating to traffic conditions on the network (speed at certain locations, journey time etc) thus building a real-time dynamic network model of traffic conditions

Nomadic devices should also be differentiated by their communication technology and especially the communication range. Many Bluetooth devices like car radios and headsets for example have no GPS, and consequently cannot communicate their position. Instead, Bluetooth scanning devices 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 (section 5.5).

Nomadic devices with long range communication, typically 2/3G cellular devices, can be divided the presence or absence of positioning, typically GPS. Here we will focus on devices with GPS only, as these can send direct information about their position and speed from any location and time. In contrast to the Bleutooth scanning above, 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 [9].

5.7.2 Current Operational Experience

Bluetooth Scanners

Bluetooth scanning technology is being developed into commercial products and services. In a field test in 2010 [29], the performance for travel time estimation and congestion detection was evaluated on part of the road network around Rotterdam. When scanners are placed at strategic locations, the travel times can be estimated from the devices that pass multiple scanners. Especially anomalies in travel time due to congestion could be detected. An interesting finding was that the number of Bluetooth devices was usually more than 40% of the number of passing vehicles (detected with existing loop detectors) and even more in HVG in the port area. Although vehicles may contain multiple devices, the penetration rate seems sufficient for travel time estimation.

A major advantage is that the installation of the scanner is very flexible; i.e. it does not require accurate mounting or callibration as it does not require a line of sight to the vehicles or devices.

There are also disadvantages that limit the functionality of traffic monitoring and incident detection. The orientation and configuration of the Bleutooth scanners is not sufficiently well developed. The road side scanner only detects the presence of a BT device in its vicinity, but cannot differentiate the location, distance, heading or speed of the device. The scanner cannot distinguish between mulitple devices in a single vehicle, or devices in different vehicles, devices on adjacent roads, of cyclists or pedestrians, etc. Strategic location of the scanners is essential to minimize the risk of non-vehicle bound devices. Nevertheless, the technology appears to be less suitable for vehicle counting and derived traffic data. The general conclusion from [29] is that this is not a mature technology yet.

Navigation devices

Nomadic devices with a GPS sensor are becoming very popolar and wide spread. Navigation systems for example, are commercially available in large numbers. Navigation devices with frequent communication via cellular networks can collect traffic data live to estimate the traffic state in the road network. A major advantage is that this provides also traffic state information on secondary and urban roads, in addition to the primary road network. The service providers collecting this traffic information are commonly not the road operators and road authorities, which implies that this information has to be acquired for traffic and incident management.

Currently, the nomadic devices are only used for route planning, travel time prediction and detection of congestion. Other incidents, like accidents and broken down vehicles, or eCall functionality are not yet integrated.

5.7.3 Recent and Future Developments

The future capabilities and potential for utilizing these technologies will be explored in detail during phase 3 of this study. Initial review highlights the following considerations and potential limitations as key to the suitability of these technologies:

- 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 be equipped with the technology 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 equipped vehicles
- Data fusion – there are numerous types of technologies and suppliers of systems. As indicated above, a successful system will require substantial proportion of equipped 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.
- Privacy – there are still issues to be sorted out internationally with privacy of data that is being communicated with nomadic devices, especially for the scanning of general purpose Bluetooth device where the owner is not aware of the detections.

5.8 In-Vehicle Systems

In the context of this project and incident detection, we consider systems or devices in-vehicle systems if they are integrated with systems and sensors in the vehicle and have functionality to detect vehicle manouevres, weather and road conditions. In contrast, devices and systems in a vehicle that are not connected to the vehicle sensors are considered nomadic devices in this project (section 5.7). Examples of in-vehicle systems are eCall systems and on-board units for cooperative systems.

5.8.1 Background to Technology

Cooperative systems are systems in vehicles, road side units, traffic centres and back offices that cooperate to improve traffic throughput, safety and the environment. In several generations of national and international research projects like SAFSPOT [30] and DRIVE-C2X [31], systems are developed in vehicles and at the road side that cooperate to detect and respond to incidents. These systems provide major advantages for incident detection and management over strictly infrastructure-based systems as previously described in detection and response:

- Information from the vehicle can be directly acquired and used to predict and detect incidents.
- Drivers can be warned directly, and vehicle systems can be invoked immediately, to avoid or mitigate an incident.

Systems in the vehicles can have direct access to the vehicle sensors and systems, and run functions to monitor, detect, and respond to a wide range of incident-related situations. These functions of DRIVE-C2X cover the range of incident types of section 3 with functions like the traffic jam ahead warning, slow vehicle warning, car-breakdown warning, emergency electronic brake lights, obstacle warning and post crash warning.

The vehicles and road side systems can communicate with each other to exchange warnings and other information to increase the situational awareness. Upon detection of an (eminent) incident by one vehicle, the other vehicles and road side systems are warned immediately. Likewise, if the existing infrastructure based systems detect and incident, they can also warn the equipped vehicles immediately.

The vehicle systems respond by warning the driver via a display of the eminent danger of the conflict or incident. Alternatively, the vehicle systems may also intervene automatically to avoid accidents. In SAFESPOT [30] the safety margin concept is defined in which the time before a potential incident is divided into three zones; comfort, safety and critical. These zones are defined in terms of the conflicting trajectories and the time prior to a potential conflict, and are computed from vehicle, driver and environmental parameters. Detection of potential accidents requires the detection and prediction of vehicle trajectories.

Potentially, the detection delay and response time can be reduced dramatically over existing incident management approaches. The performance has not been fully assessed yet. Field operational tests are being developed to evaluate the performance in real world situations, e.g. in DRIVE-C2X.

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