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Task 4

Autonomic functions implemented in existing ITS

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Preface

This document is elaborated in the framework of Sub-activity 4.2 – Facilitating Automated Driving of the EU EIP project and represents the first deliverable of Task 4 – Automatic road side ITS systems/Automation of road operator ITS.

The Sub-activity 4.2 is divided in several tasks:

- 0. Task management.
- 1. Identification of requirements.
- 2. Impacts and economic feasibility.
- 3. Road map and action plan.
- 4. Automation of road operator ITS.
- 5. Monitoring, liaison, dissemination.

Task 4 will identify the requirements of automating the road operators´ ITS systems to facilitate automated vehicle – infrastructure integration. This includes the road side ITS systems with properties like: self-maintenance, self-optimisation, self-management, self-healing fully or partly based on specific needs. Secondly, the task will identify good and avoidable practices in implementing automatic functions on road side and traffic centre systems. Finally, the task also deals with the optimal automation level of traffic control/management/information centre operations and services.

Task 4 is coordinated by ITS Romania (Mihai Niculescu) and DGT Spain (Ana Blanco) with participating partners from FI, FR, DE, IT, NL and UK.

Acronyms

AID: Automated Incident Detection

ALPR/ANPR: Automatic License Plate Reader

AMR: Anisotropic Magnetoresistance

APID: All Purpose Incident Detection

AVI: Automatic Vehicle Identification

AVL: Automated Vehicle Location

ATIS: Advanced Traveller Information Services

CCTV: Closed Circuit Television

CW: Continuous Wave

DCS: Data Collection Station

DGT: Dirección General de Tráfico

DIVA: Dynamic Integrated Traffic Analysis

DRIP: Dynamic Route Information Panels

ESAL: Equivalent Single Axle Loading

FCD: Floating Car Data

FMCW: Frequency Modulated Continuous Waves

FTA: Finnish Traffic Agency

GMR: Giant Magnetoresistance

GPS: Global Positioning System

HFP: Historic Flow Profile

IMS: Incident Management System

ITS: Intelligent Transport System

JTS: Journey Time System

LAR: Local Algorithmic Response

LJTS: Local Journey Time Signs

LOS: Level of Service

LVDS: Logical Vehicle Detection Station

MOR: Meteorological Optical Range

MPC: Multi-Purpose Controller

NTDS: National Traffic Data System

OCR: Optical Character Recognition

PSAPs: Public Safety Answering Points

RF: Radio Frequency

RTD: Resistance Temperature Detectors

RWS: Rijkswaterstaat

SPVD: Self-Powered Vehicle Detection

SWOT: Strengths, Weaknesses, Opportunities and Threats

TMC: Traffic Management Centre

TMP: Traffic Management Plan

TMU: Traffic Monitoring Units

UPS: Uninterruptible Power Supply

UTMC: Urban Transportation Management and Control

VMS: Variable Message Sign

VMSL: Variable Mandatory Speed Limits

WAAR: Wide Area Algorithmic Response

WiM: Weight in Motion

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1. Introduction

This chapter describes the scope and objectives of the EU EIP sub-activity 4.2 as well as the description and objectives of its Task 4 according to the Grant Agreement signed with INEA.

Task 4 is named “Autonomic road side ITS systems/Automation of road operator ITS” and was initially proposed as an independent sub-activity of EU EIP project. However, in the final stages of the proposal it was included in EU EIP sub-activity 4.2 where it brings a complementary point of view on road automation and the requirements towards road operators deriving from the deployment of automated vehicles and C-ITS.

1.1. Scope and purpose

The scope of this document is to identify autonomic functions and applications existing in ITS implementations and to describe the advantages and benefits of these autonomic behaviours in ITS.

The first step is a definition of autonomic behaviour of Intelligent Transport Systems having as reference the document elaborated by IBM. [1] Based on this definition the second step is to identify the functions and applications which are already installed and to analyse them in terms of finding the best implementations of autonomic concept in real and existing ITS.

The third step is to define the future measures and development directions for implementation of autonomic behaviour at large scale in ITS domain. This third step is concluding the document.

1.2. Methodology

Based on IBM document and the results of COST Action 1102[2] the most important characteristics of autonomic systems are selected in terms of building a framework for autonomic behaviour of ITS systems, with major focus on traffic management centres.

1.3. Document structure

The document has three main parts: the definition of autonomic behaviour of intelligent transport systems related to TMCs, the identification of autonomic functions of installed ITS and next steps and conclusions.

[1] An architectural blueprint for autonomic computing - http://www-03.ibm.com/autonomic/pdfs/AC%20Blueprint%20White%20Paper%20V7.pdf

[2] https://helios.hud.ac.uk/cost/

2. Autonomic systems

2.1. General description

The term autonomic is a biological metaphor adopted by IBM to describe the desired properties of future complex IT systems, proposed as a highly advanced approach to deal with the problems of the delivery and maintenance of increasingly complex systems. Autonomic systems embody self-assessment and self-management abilities that enable the system to assess its own state, then adapt or heal itself in response to that assessment. The interface between system and owner is set at a very high level: the owner sets out goals, policies or service levels that the system must follow, and the system translates these into its system functions resulting in a change of behaviour. IBM defines four areas of autonomic functions: (i) self-configuration through automatic configuration of components; (ii) self-healing through automatic discovery, and correction of faults; (iii) self-optimization through automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements; and (iv) self-protection through proactive identification and protection from arbitrary attacks.

2.2. Functions

The implementation of autonomic functions in the operations of traffic management centres could bring important benefits in increasing their efficiency and performance. The main reasons are the decrease of workload for the operators and, by processing large amounts of relevant data, the potential to find better solutions than a human operator. An autonomic system should be designed to have self-* properties as a whole, not only at the level of individual components / subsystems.

The authors believe that in order to achieve these benefits, traffic centres should implement at least four high-level autonomic functions:

- self-management
- self-optimizing
- self-healing
- self-configuration

Also the following supporting autonomic functions should be implemented:

- self-learning
- self-diagnostic

The self-management function describes a system that is able to automatically decide how to react and plan the traffic management actions. One example could be that in case an incident is detected the system decides how to present and what information to show to the operator so it is most relevant and most helpful for her/him to take action.

Self-optimizing is another key function for an autonomic system. It defines a system that, given certain requirements, can automatically find the best solutions for a certain situation. In a traffic centre, this could be, for example, computing the best rerouting option for the drivers in case of an incident. Or, based on the traffic conditions, the system can automatically calculate and apply dynamic speed limits.

Self-optimizing also applies to the actual operation of the hardware within the traffic centre. One example would be automated management of the power consumption depending on how much demand the traffic situation and traffic management requirements put on the system.

The self-management and self-optimizing functions have to be supported by a self-learning capability allowing the system to "learn" how to react based on historical data.

Self-healing is straightforward: the system can automatically heal itself and continue normal operation when one or more components fail. Of course this applies only to a certain extent and is expected that major failures will cause the system to stop. The self-healing function has to be accompanied by a self-diagnostic capability allowing automated detection of the errors and failed components.

The forth proposed function is self-configuration. It means that a system is able to automatically adapt its operations whenever there is a hardware change or upgrade. For example, if new sensors are connected, the system should detect them, use their data and expand its services taking advantage of the new available information.

2.3. Benefits for road operators and road users

The autonomic systems are a good investment for road operators in terms of returning their investment not directly into money but as organisational and administrative benefits. One of the most important indicator for road operator's activity is the time of response in the case of an incident or a malfunction of the system. This situation is better solved if the system has the capability to do itself the action and decision needed. The autonomic functions could be the solution. Another important indicator of the activity of road operator is the number of incidents or failures which are solved in a short term and with a small amount of resources (especially human resources). The autonomic behaviour will be the way to not use the human resources in a various types of incidents and to solve the problem in shortest time. Another important benefit of the autonomic systems is the assistance of human operator in taking the decision and the application of strong algorithms to take the best decision in a given context. Automation may also improve the coverage of the TMC monitoring system since the automation and related big data handling may be able to monitor, combine and analyse the data from numerous sources simultaneously.

TMCs with autonomic behaviour could also cope better with security issues based on self-healing and self-configuration functions. On the other hand, the fact the autonomic TMCs

are trusted to take decisions on their own means that security is more critical and external attacks on the system have to be prevented much better than in traditional systems.

The road user benefits are merely indirect, since the implementation of autonomic functions as well as the autonomic systems could increase the safety and the level of ITS services through the accuracy of taking the decision, the reduction of time and the implementation of complex algorithm for solving the problems, which will, further, benefit the whole society as described in the following chapter.

2.4. Benefits for the society

For the society the benefits of implementing autonomic functions and systems are categorised into two groups: the safety related benefits and the service quality related benefits. It can be expected that the benefits are seen only if there are also respective traffic management measures that can adjust the management based on the faster decisions by the autonomic systems.

The group of safety related benefits is formed by the following benefits:

- The increasing of general level of safety on the road where the autonomic functions or systems are implemented;
- The avoidance of human errors in terms of taking the decision and solving the complex problems generated by incidents and failures;
- The increasing the operator's speed of reaction aftermath an incident and the reduction of time between the beginning of an incident and the intervention of the road operator;
- The increasing the reliability of the system and the duration of life for all systems which are self-healing oriented;
- The integration and interoperability between autonomic systems will be better solved in terms of increasing the safety on road.

The group focused on service quality is formed by the following benefits:

- The decision of the system will be taken better and in shorter time;
- The general quality level of ITS services will be increased;
- The real time data as well as safety and sensitive data will be available in right time and the decision based on this data will be most accurate and responsive than a human operator can take.
- The better monitoring of the system as well as the quality control will be done by the system itself and the reporting procedure will be cost and time efficient.

The typical KPIs used for benefits for society as such as accident reduction (especially fatalities, injuries), better traffic flow (e.g. reduced congestion, time lost due to congestion), and reduced energy consumption and hence CO2 emissions.

2.5. Implementation costs

The cost of implementation has to be correlated with the level of autonomy which is specified and the scale of the implementation (how many functions are implemented in the system).

The costs of implementation of autonomic components has at least the following elements:

- The cost of implementation of software functions
- The cost of implementation of hardware components (central system + needed roadside monitoring systems)
- The cost of integration of autonomic functions in the system
- The cost of human resources involved in the system
- The additional costs (re-design etc.)

2.6. Operation aspects

2.6.1. Operation and maintenance costs

The costs of the operation and maintenance are generally expected to be lower than the systems without autonomic implementation but the nature of the cost is somehow different. The maintenance is shared between humans and the self-healing and self-maintaining sub-systems. The cost of maintenance is higher at the implementation stage of the autonomic systems and functions and it will be reduced during the operation of the system. The complexity of the systems is higher and this complexity will affect the maintenance procedures and the need for high qualified human resources.

The operation costs are lower than a system without autonomic implementation and the first reason is the decreasing of human intervention in the system and the reduction of the effects of human errors. The time for human based diagnosis is reduced and the self-intervention for healing and optimisation is better than human action for the same activities. The operation costs are related more to the reliability of the system than the human level of competencies and abilities to operate the system.

2.6.2. Risk analysis

The main risks which occur during the operation of autonomic systems are:

- The low reliability of the system and the need of human intervention
- The lack of training for this type of the system
- The lack of procedure in case of system failure; also a long term effect of degradation of the manual operation skills (not needed often)
- The lack of stability of autonomic functions in case of human/machine intervention

- The lack of confidence in autonomic system, especially for traffic centre operators
- The low predictability of cost could generate extra costs

For all risks, the road operators have to find a list for risk mitigation and avoidance of the risk factors as well as the procedure for the intervention in the case of risk occurrence. The risk plan and the risk control could be also implemented in autonomic manner based on the automatic collection of the data from the system and the decision taking in autonomic manner.

3. Existing traffic management centres with autonomic functions

Today traffic management centres require complex dedicated software to support road operators in their tasks. The software collects vast amounts of data regarding the traffic conditions and other relevant information (e.g. weather data), analyses them and presents to the operator aggregated data or even automatically calculated solutions to improve traffic management. It is expected that the more automated or autonomic a centre is, the easier and more efficient it would be for the operator to perform his/her tasks.

Although automation and autonomic functions are currently not widespread among traffic centres, there are some that employ such technologies. Because of that, the term "automated/automatic" will be mostly used in the following sections instead of "autonomic".

3.1. Traffic management actions

3.1.1. TRAFFIC CONTROL CENTRE HESSEN

Traffic Control Centre Hessen operates based on currently detected and forecasted traffic conditions. It collects data from about 5.000 traffic sensors on motorways regarding speed and traffic volume data, but also environmental data (e.g. temperature). The data is processed and analysed in order to model current traffic situation, current travel time/ travel time loss and to forecast congestion with DIVA (Dynamic Integrated Traffic Analysis) methods.

There are three major operations that are performed automatically at Control Centre Hessen:

- network control
- line control
- roadworks/slot management

Network control deals with distribution of traffic within the motorway network to avoid congestion and a traffic collapse and in case of any incident. As shown in **Virhe. Viitteen lähdettä ei löytynyt.**, the information is displayed on VMS and is selected automatically as:

- time loss if it is >5 min
- rerouting if time loss > 10 min and travel time advantage accrues

Figure 3.1.1. Example of network control information (source: Hessen Mobil)

The line control system calculates and displays variable speed limits to harmonize traffic flow as can be seen in Figure 3.1.2. . It also handles temporary hard shoulder running, dynamic HGV overtaking ban and dynamic danger alerts (congestion warning, weather alert, broken down vehicle warning, temporary hard shoulder running etc.).

Figure 3.1.2. Example of line control system in Hessen (source: Hessen Mobil)

The slot management system automatically checks if the transport system can handle a roadwork and determines suitable time slots for projected works on motorways.

Figure 3.1.3. Slot management system (source: Hessen Mobil)

As shown in Figure 3.1.3, possible timeslots for any planned short term road work are calculated as result of the evaluation in terms of their effects on traffic. After selecting the road section and the number of blocked lanes the system calculates possible timeslots based on traffic data, expert knowledge and rules. These timeslots are presented in green. Timeslots which are marked in red cannot be selected due to the risk of congestion.

3.1.2. SPANISH TRAFFIC MANAGEMENT CENTRES

There are many automated functions implemented in Spanish Traffic Management Centres (TMC).

In Spain, there are actually eight TMC's, located in Madrid, Valencia, Málaga, Sevilla, Zaragoza, Valladolid, A Coruña and Baleares. Each one manages a determined area as shown in Figure 3.1.4. .

Figure 3.1.4. Traffic Management Centres in Spain (source: DGT)

3.1.2.1. JOURNEY TIME INFORMATION

The main object of this tool is to provide an estimation of how much time would need a standard vehicle to complete a determined distance.

This automation is based on theoretical calculations given by predefined rules inserted in the system. In this particular case, the automatic system will check whether the time criteria are met and it will be responsible for sending a message automatically to the VMS assigned for the signalling.

Some examples of calculations at the Southeast Traffic Management Centre are explained in detail in Figure 3.1.5. for two sections located in A-7 and AP-7 (one for each direction).

Figure 3.1.5. Travel times signalling between Málaga and Marbella (source: DGT, Southeast TMC)

The criteria used for establishing the automatic signalling dispatch for the direction from Málaga to Marbella are given by the following table:

Table 3.1.1. Criteria for automatic signalling dispatch for the direction from Málaga to Marbella

	Travel time for the whole section A-7 (min)	Average speed for the whole section A-7 (km/h)	Travel time for the whole section AP-7 (min)	Average speed for the whole section AP-7 (km/h)	Difference A-7 y AP-7
LOS "A"	22:50	83,46	15:48	106,45	07:02
LOS "E"	**25:03**	76,12	15:48	106,45	09:15

The parameter considered for the automatic signalling dispatch is given when Level Of Service (LOS) E is achieved in A-7. In other words, when the time of the travel exceeds 25 minutes, in this moment, the difference between A-7 and AP-7 is about 9,15 minutes, with a deviation of 37% of travel time in both roads.

The message shown on the VMS will be generated according to the calculations made by the system.

In the same way as in the case above, the criteria used for the direction from Marbella to Málaga is:

Table 3.1.2. Criteria for automatic signalling dispatch for the direction from Marbella to Málaga

	Travel time for the whole section A-7 (min)	Average speed for the whole section A-7 (km/h)	Travel time for the whole section AP-7 (min)	Average speed for the whole section AP-7 (km/h)	Difference A-7 y AP-7
LOS "A"	31:00	91,93	23:19	113,14	07:41
LOS "E"	**33:03**	86,22	23:19	113,14	09:44

For this section, the automatic signalling dispatch will be sent for a LOS E in A-7. When the travel time exceeds 33 minutes of the travel time direction Málaga, at that instant, the difference of times between A-7 and AP-7 is about 9,44 minutes, with a deviation of 29% of travel time in both roads.

This Centre manages the "Automatic deployment of signalling plans" with a specific tool.

The feature shows all the VMS that can be modified and asks for a priority to signalling by default, in case there is no signalization. The main dialog window is shown in Figure 3.1.6.

.

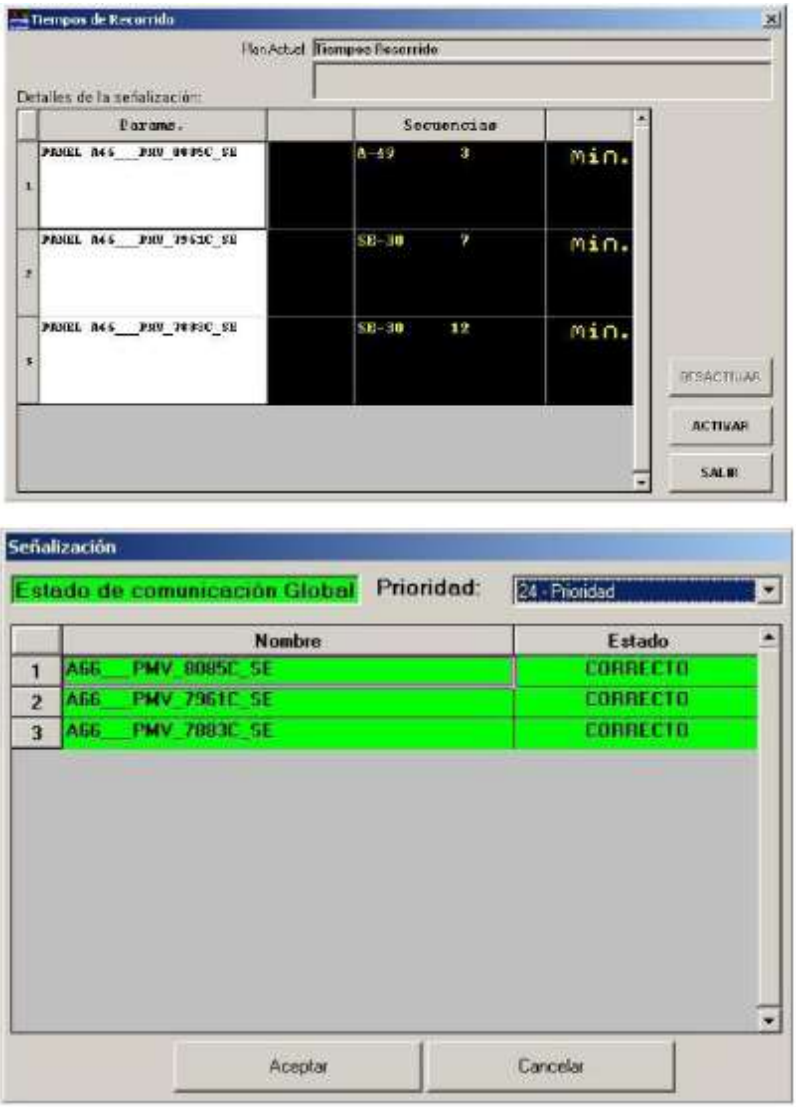

Figure 3.1.6. Application dialogs for travel times signalling (source: DGT, Southwest TMC)

There are three kind of priorities A, B and C. The behaviour of the tool will depend on the priority used for the signalization. In case there is more than a priority, only will be considered the prime one.

The interface of the application (Figure 3.1.7.) allows making changes on the configuration, defining priorities and specific messages for each case.

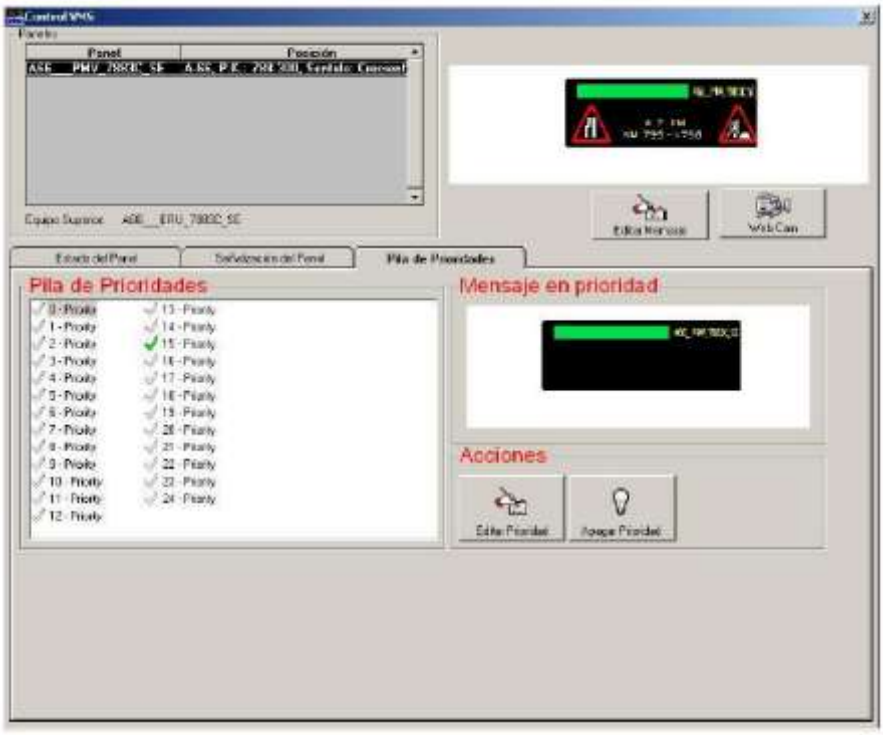

Figure 3.1.7. Control VMS dialoge for travel times signalling (source: DGT, Southwest TMC)

There are many options and filters that allow the customization of the main signalizations (order, activation, priority, etc).

All these options will be checked and supervised by traffic operators to ensure the target of the automatism.

3.1.2.2. POLLUTION MEASURES SIGNALLING

In order to carry out the control of the air quality, Madrid has a Vigilance, Prediction and Information of Air Quality System, which allows to know, in every moment and real time, the concentrations of pollutants, with the aim of protecting the health of the population and reducing risky situations.

The alert threshold for the nitrogen dioxide has not been overcome never on the municipality of Madrid, unlike the hourly limit value which has been exceeded in many stations of the net. The high concentrations are mainly caused by traffic emissions, and they take place usually on adverse meteorological conditions, which require the implementation of measures in order to reduce contamination levels and duration of episodes, avoiding the overcoming of hourly limit values and alert threshold.

For this reason, a division is established in the municipal territory, in such a way that in alert situations, measures can be defined depending on the population density of each area. Also, depending on the levels achieved and the duration of episodes, traffic

restrictions in the city and in its accesses can be implemented in order to reduce contamination levels.

The zoning of the municipality (Figure 3.1.8.) is made considering:

- Population distribution.
- Type and distribution of vigilance air quality stations.
- Traffic infrastructure, in order to facilitate the implementation of the restrictions.

Figure 3.1.8. Municipal division for pollution management (source: DGT, Central TMC)

There are three action levels depending on the nitrogen dioxide concentrations:

- Pre-warning: when in two stations of the same zone, concentration levels overcome 180 micrograms/m3 during two consecutive hours.
- Warning: when in two stations of the same zone, concentration levels overcome 200 micrograms/m3 during two consecutive hours.
- Alert: when in three stations of the same zone (or two if it is zone four), concentration levels overcome 400 micrograms/m3 during three consecutive hours.

Once one of these levels has been overcome and, if the meteorological prediction is not favorable, an episode of contamination will be considered as started. The measures for each scenario are explained below:

- Scenario 1. One day with overcoming pre-warning level.
    - Informative measures 1[3]

[3] The information will be accessible for the population, with simultaneous warnings to politicians, municipal departments and organizations related to health and environment. It will inform about the values achieved, the

- Traffic speed restriction to 70 km/h in M-30 and accesses.
- Promotional measures of public transport.

- Scenario 2. Two consecutive days with overcoming pre-warning level or one day with overcoming of warning level.
  - Informative measures 1 and 2[4]
  - Traffic speed restriction to 70 km/h in M-30 and accesses.
  - Prohibition of parking in SER (regulating parking service) places inside M-30.
  - Promotional measures of public transport.
- Scenario 3. Two consecutive days with overcoming warning level.
  - Informative measures 1 and 2
  - Traffic speed restriction to 70 km/h in M-30 and accesses
  - Prohibition of parking in SER (regulating parking service) places inside M-30
  - Traffic restrictions inside the central core (interior area of M-30) of the 50% of all vehicles
  - Promotional measures of public transport
  - It is not recommended the circulation of free taxis, except Ecotaxis and Eurotaxis inside the central core, being these vehicles authorised to park in SER places in addition to in its habitual stops.
- Scenario 4. Three consecutive days with overcoming warning level or one day with alert level.
  - Informative measures 1 and 2
  - Traffic speed restriction to 70 km/h in M-30 and accesses
  - Prohibition of parking in SER (regulating parking service) places inside M-30
  - Traffic restrictions inside the central core (interior area of M-30) of the 50% of all vehicles
  - Traffic restrictions in M-30 for the 50% of all vehicles
  - Promotional measures of public transport

hour and the place where the levels have been registered, as well as a prediction of the evolution and recommendations. In the same way, traffic restrictions and promotional measures of public transport will be announced.

[4] In addition to informative measures 1, Health Environmental Alert System will be activated.

- It is not recommended the circulation of free taxis, except Ecotaxis and Eurotaxis inside the central core, being these vehicles authorised to park in SER places in addition to in its habitual stops

All these measures will be applied as soon as possible after being achieved any of the described scenarios. Promotional measures of public transport will be applied simultaneously to traffic restrictions. And finally, all these actions will be deactivated when the concentrations achieve normal values.

3.1.2.3. AUTOMATIC SYSTEM FOR AVOIDING REAR END COLLISIONS

The estimation and prediction of a possible impact is broadly based on the interval between consecutive vehicles while passing through a detector. Depending on the timeframe between a vehicle and the consecutive, the dynamic lighting of the signals will be activated.

The system is capable of switching on one or more signals associated with each detector, because the operation of detectors and signals are independent. Two signals will be connected to one detector as maximum, because of the location of the signals along the ramp.

The dynamic signalling for indicating the detection of a possible impact will depend on the variables obtained by the detector and the management software: intensity and interval between vehicles.

The operation of the algorithm is based in the estimation of:

- Intervals
- Lighting up time of the signals

When the interval, which is the lapse of time between consecutive vehicles passing through a determinate point of the lane, is between a minimum and a maximum time predefined, the lighting up of the signals will be activated.

The detector measures the interval between vehicles passing from the front bumper of the first one to the front bumper of the consecutive.

The lighting up of the signals will depend on the interval between vehicles. There are multiple options according to the interval, the activation of the first signal, the first one and the second or none of them. In case of being necessary the lighting up of both signals associated with the detector, a delay between the activation of signals must be considered.

3.1.2.4. ACTIVATION OF REVERSIBLE LANES

The operation of reversible lanes on the SE-30 ring road (related to the V Centenario Bridge) between kilometre points 10+000 and 12+000, is a reference example of using reversible lanes.

The ring road SE-30 is composed by three lanes in each direction along practically the full length except in the area of the Centenario Bridge, where the section presents two lanes in each direction separated by a concrete median. In order to avoid the loss of capacity

caused by the change of section, in 1992 the reversible lanes were installed with a length of 1000 meters.

The elements of the signalling system are:

- 4 VMS: located at the beginning of the reversible lanes, two for each direction.
- 96 Lane signals: two signals for each lane distributed in seven simple gantries (cover only one lane direction), and four double gantries (cover the lanes of both directions).
- 244 Beacons: they delimit the lane depending on the traffic sense.
- 7 Data acquisition stations (ETD's): they provide information about the vehicles that circulate around the same lane.
- 10 Universal remote station (ERU's): for managing the rest of the equipment.
- Communications systems: composed by 7 routers.
- Fibre Optic network.
- SCADA signalling system servers.
- Operation clients of SCADA signalling system.
- 2 Uninterruptible Power Supply (UPS) and 2 electricity-generation group.

The change of the direction on reversible lanes takes approximately 100 seconds, enabling to adapt the configuration of the Bridge to traffic needs rapidly.

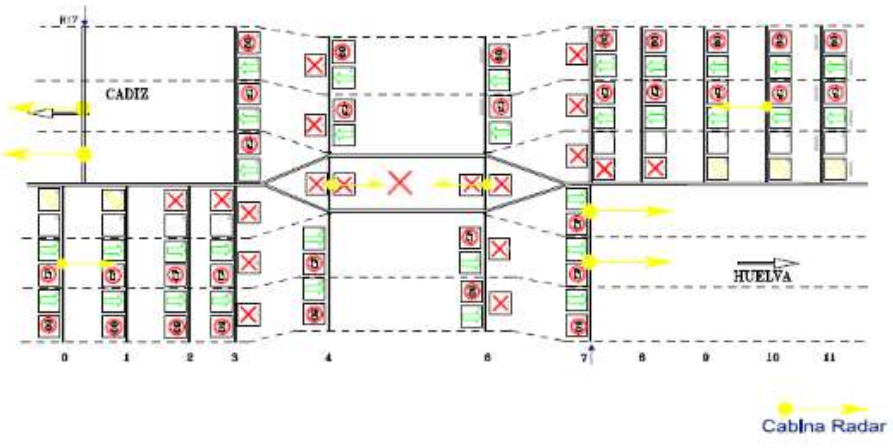

Figure 3.1.9. V Centenario Reversible Lane Signalling (source: DGT, Southwest TMC)

To decide in which moment is necessary to activate the reversible lane, the system provides traffic management operators, each minute, traffic intensity data (vehicles that want to cross the Bridge in each sense), as well as the average speed and the percentage variation of traffic intensity.

In addition to traffic demands related to crossing the Bridge, for its operation, it is necessary to evaluate traffic conditions in adjacent areas. It will not be a suitable strategy to open the reversible lane direction to Huelva although there is more traffic intensity if 800 metres ahead, on the Queen Sofía Bridge there is a traffic congestion, because more vehicles will be added to a congested zone. Therefore, to operate the reversible lane, it will be necessary to consider the situation of the Bridge and the SE-30 ring road.

The steps in order to activate reversible lanes are:

- Turn on the SCADA System
- Select the option “Reversible Lane” on the menu.
- Visualize a window (Figure 3.1.10) with the current signalization of the Bridge and the status of the different panels.
- Clicking twice over the scheme of the Bridge, there is a window titled “Signalling test” (Figure 3.1.10). On this dialog, it is possible to check the last status sent, as well as the user and date of signalization.

a) *b)*

Figure 3.1.10. V Centenario Bridge signalization dialog (a) and test (b) (source: DGT, Southwest TMC)

Changing the signalling of the Bridge can be made in two different ways: manually forcing the signalization as described above, or by automatically applying the different signalling transitions configured in the system.

3.1.3. T-LOIK IN FINLAND

In Finland, many traffic management actions are currently semi-automatic in the sense that the systems automatically deduce the appropriate traffic management actions, e.g. the change of the dynamic speed limit based on the development and short-term forecasts of road weather related indicators. The actual action, in this case, the change of the speed limit will be executed by the traffic centre operator by accepting the system proposal or by carrying out some other action.

Figure 3.1.11. Weather controlled Variable Speed limits (source: FTA)

European ITS Platform

In Finland, automated data acquisition is routinely carried out by hundreds of traffic monitoring stations, road weather monitoring stations, and CCTV cameras. The data is sent by the stations at intervals of 1-20 minutes. In addition, AID (Automated Incident Detection) is in operation in selected critical spots and sections, mainly tunnels. The diagnostics of roadside ITS has also been implemented so that whenever the roadside station or the central system polling the roadside station observes a malfunction, this is automatically reported to the traffic centre operator and/or the contractor responsible for the operation and maintenance of that particular station.

A key aspect of data acquisition is to obtain data on incidents on the network. One key source for this data is the emergency centre organisation managing the PSAPs (Public Safety Answering Points). In Finland, the emergency centre's accident and incident data base sends automatic messages to the traffic centres concerning the location, type, severity and other features of the accident or other incident in question.

In Finland, other road operator actions include requests for actions from the different contractors responsible for road and winter maintenance, operation and maintenance of roadside infrastructure, and other road network operation related tasks.

3.1.4. TRAFFIC SCOTLAND SYSTEMS

Traffic incident management and information dissemination within Scotland is not dissimilar from that provided elsewhere across Europe. This function is delivered by the Traffic Scotland service, which is the brand name for the service provided to the travelling public by the Scottish Government's transport agency, Transport Scotland. Information on the Traffic Scotland service can be found at the public website: www.trafficscotland.org. Information on Transport Scotland can be found on the agency's website: www.transport.gov.scot. The service covers the trunk road and motorway network across Scotland.

There are a number of different ITS systems that are run in conjunction to provide a suite of tools to allow the Operator to manage the road network. These systems include Incident Management; Fault and Asset Management; CCTV; National Traffic Database, Journey Time; Web and Information based services.

3.1.4.1. QUEUE MANAGEMENT

One of the most frequent uses of traffic monitoring within the IMS is to automatically detect transients and the formation of Queues. The purpose of Queue Management is to identify and track queues so that appropriate information and warnings can be disseminated, for example:

- To use Signals (MSUs) and VMS to alert traffic upstream of the queue in order to protect the tail of the queue from rear shunt type accidents caused by traffic having to brake suddenly when stationary vehicles are encountered.
- To inform drivers well in advance of the presence of queues so if feasible they can use alternative routes.
- Within a queue set VMS to keep drivers informed of the queue's extent.
- Within a queue set MSUs to the In-Queue aspect (flashing ambers) to indicate the traffic hazard.
- At the end of the queue display 'End' to indicate the hazard has cleared.

Within the IMS a queue is handled as a type of Incident, the details of the Incident are updated as the queue develops. The system automatically detects queues, modifying their details in order to track them as they develop, and eventually clears the queue when it dissipates. Queues are dynamic in that they can diverge and merge, expand and contract. Updating, tracking and responding to queues forms the process of Queue Management.

A key component part of successful Queue Management is the automatic use of MSUs (Signals), Hazard Flashers, and VMSs as part of the Local Algorithmic Response (or LAR) Queue response to Incidents (example screenshot in Figure 3.1.12 below). In additional

VMSs can be set as required by the Wide Area Algorithmic Response (or WAAR) Queue response to the Queue Incident.

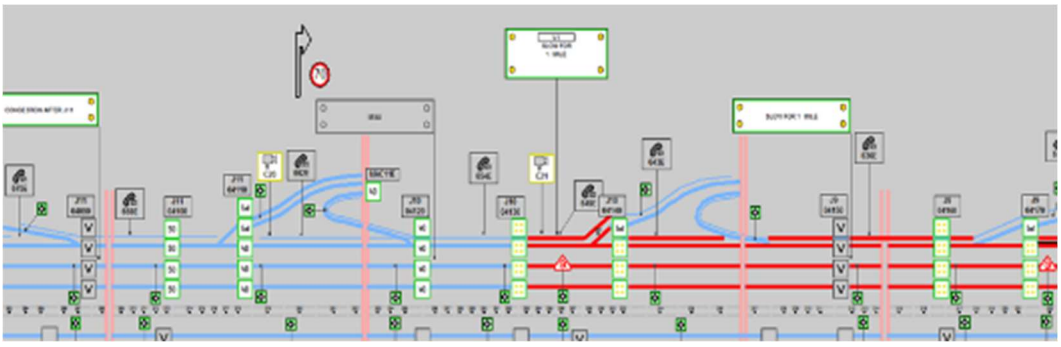

Figure 3.1.12. Example of Queue Management and LAR (source: Transport Scotland, IMS)

The LAR provides supplementary 'Local' information to drivers within the queue, such as "Congestion after J11" and "Slow for x Miles", to minimise potential driver frustration.

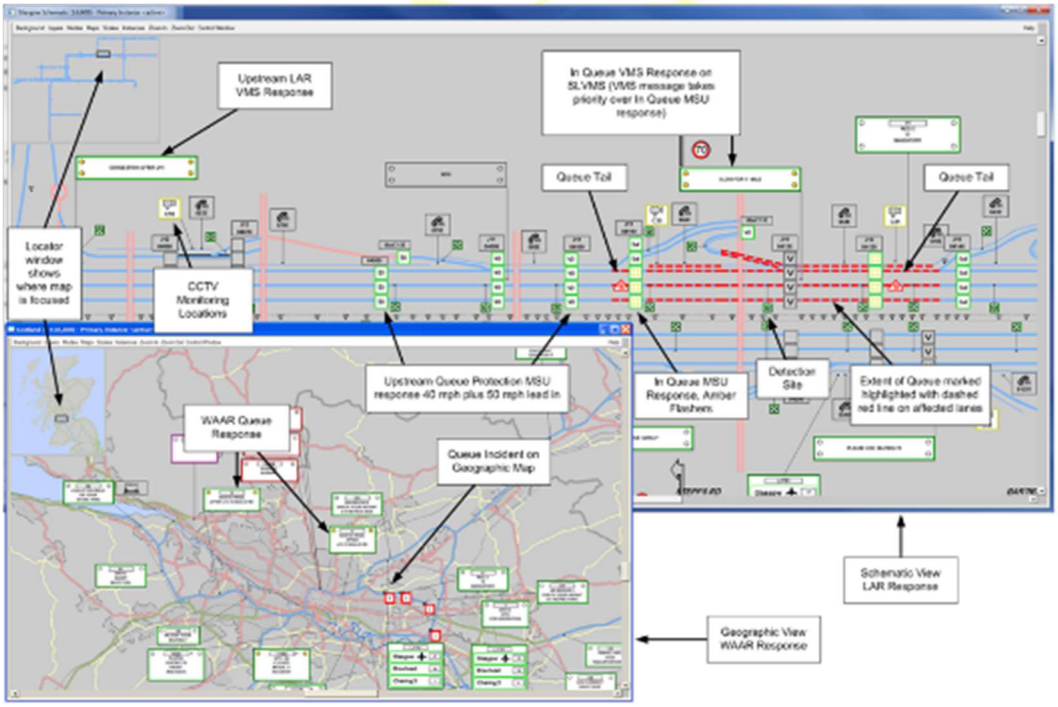

Figure 3.1.13. Example of Queue Management and supporting response algorithms (source: Transport Scotland, IMS)

3.1.4.2. *Bus Lane and Bus Hard Shoulder Running*

Within the Incident Management System, there are two forms of controlled Bus Lanes. The first is referred to as Bus Lane Running, where the nearside lane on the motorway is a dedicated permanent Bus Lane. In this situation by default the lane is permanently signed and in operation as a Bus Lane. The managed Motorway operation of the IMS assists the

Operator to monitor the operation of the Bus Lane and close it if required using Lane Signals and Variable Message signs where an Incident such as a breakdown occurs that means it no longer safe for Buses to use the lane. An example screenshot is shown in Figure 3.1.14 below.

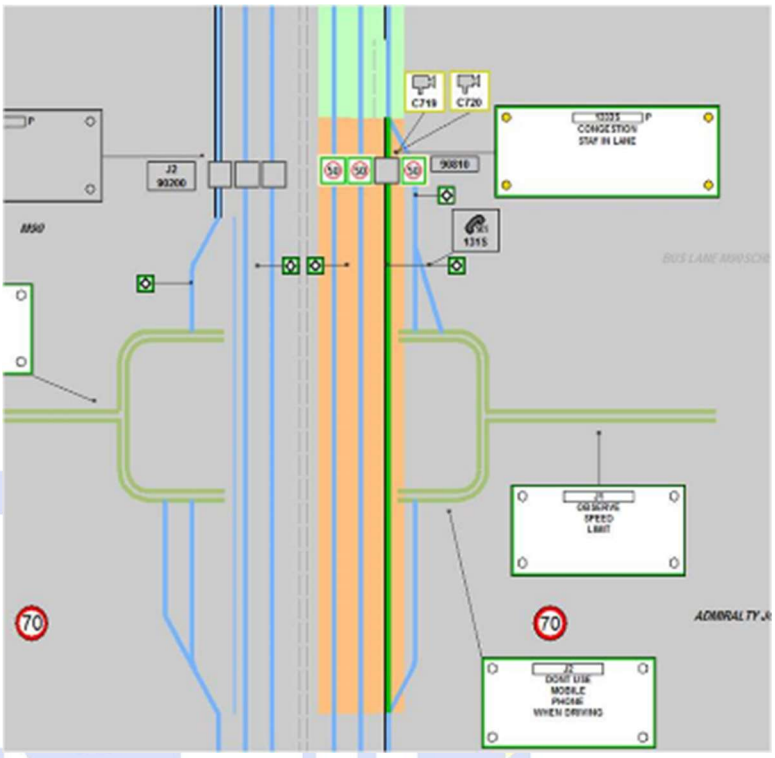

Figure 3.1.14. Example of Bus Lane Running on IMS (source: Transport Scotland, IMS)

The second form of Bus Lane is referred to as Bus Hard Shoulder Running illustrated in Figure 3.1.15. In this instance the nearside lane on the motorway by default is, and signed as, a hard shoulder (emergency lane). During specific instances, such as high congestion, the managed Motorway operation of the IMS assist the Operators in the opening up of the hard shoulder as a dedicated Bus Lane by the use of Variable Message Signs and signals.

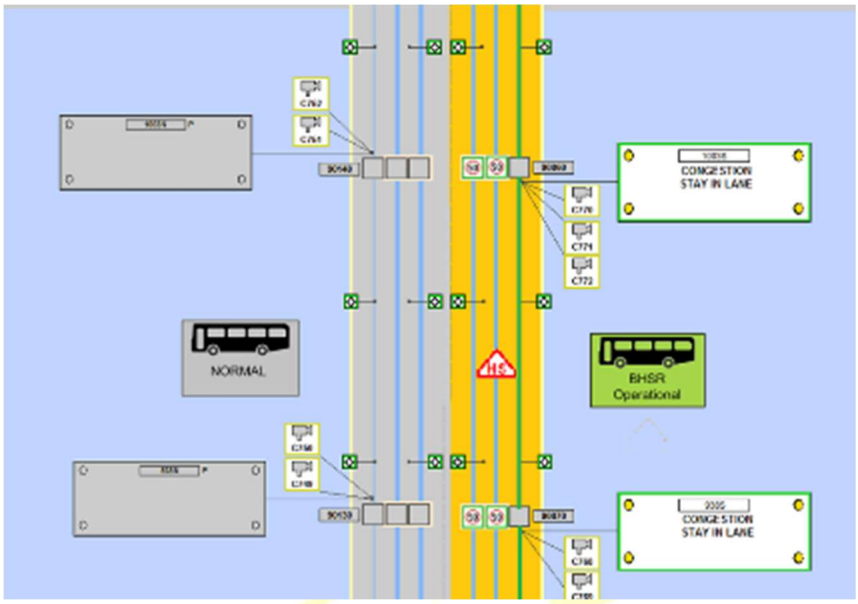

Figure 3.1.15. Example of Bus Hard Shoulder Running (Source: Transport Scotland, IMS)

Where Bus lanes are implemented, a number of Refuge areas have been constructed to allow safe stopping points so that broken down vehicles do not obstruct the Bus Lane.

The system automatically monitors whether any vehicles have entered a Refuge in order to alert the Operators to the potential hazard created by vehicles leaving and recovery vehicles entering it while the Bus Lane is in operation. In such circumstances the system can automatically shut the Bus Lane to buses and treat the Bus Lane as a Hard Shoulder (emergency lane). Automated alerting and validation through the use of CCTV is a key feature of all operations. A screenshot of the CCTV system is shown in Figure 3.1.16.

Figure 3.1.16. CCTV control system (source: Transort Scotland)

3.1.4.3. TRAFFIC SCOTLAND INFORMATION SERVICES

The Traffic Scotland website, www.trafficscotland.org is the primary portal for public information on real-time and predicted traffic conditions. The website, Figure 3.1.17, is updated automatically from the IMS, with details of current incidents, journey times and snap shot images from the bulk of the Traffic Scotland CCTV cameras, and provides access to the Traffic Scotland internet radio service.

The Operators are provided with a web based Content Management System, that allows them to among other things add editorial and parochial information to the data feeds that are provided automatically from the IMS. The Operators are provided with a dashboard view that displays the status of the information feeds being provided on the web site.

The displayed camera feeds are configured in order that they are automatically blocked from publication on the website if they are taken under control by the Operators, or have not been updated with new images within a configurable time period. The Operators can manually block publication of specific cameras, Figure 3.1.18.

DATEX II and FTP data feeds are available for stakeholders and the public to subscribe to which are automatically updated with the latest information received by the IMS, Journey Time System, CCTV system, Web site etc.

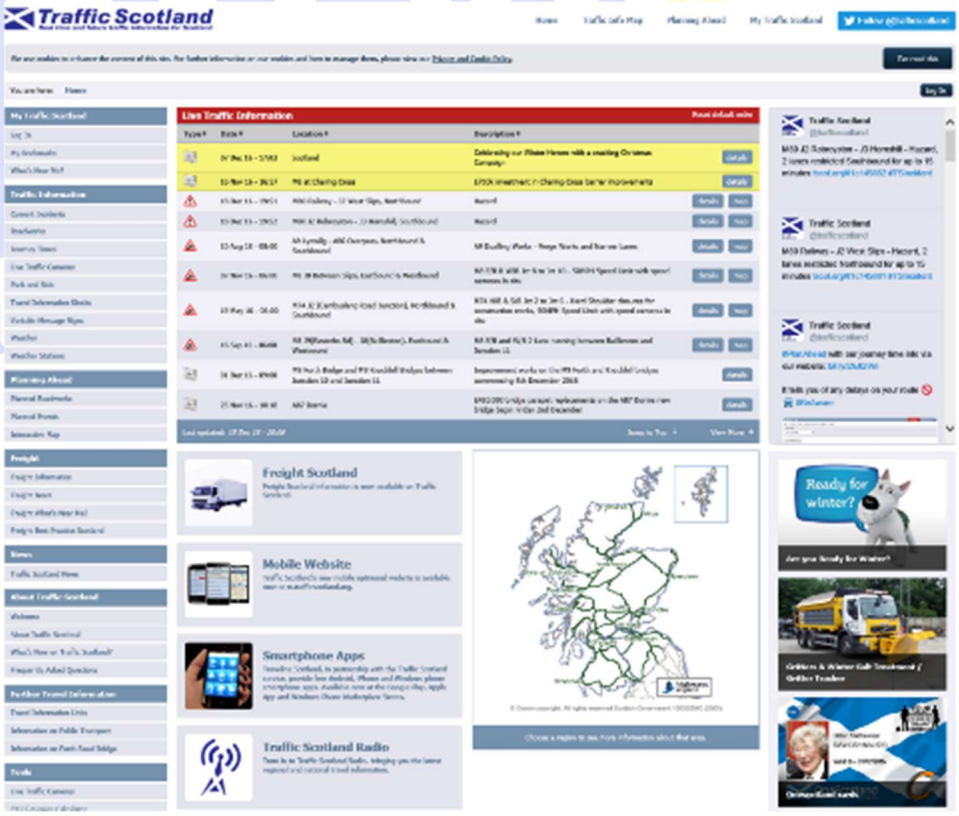

Figure 3.1.17. Traffic Scotland Website (source: Transport Scotland)

Figure 3.1.18. Example of Content Management System (source: Transport Scotland)

3.1.4.4. NATIONAL TRAFFIC DATA SYSTEM

The National Traffic Data System (NTDS) is Transport Scotland's system for traffic count data collected across the Scottish Trunk Road Network. The NTDS is linked to over 1,800 automatic traffic counter sites covering the network, including those that are connected directly to the IMS. Data collected and stored includes speed, volume and composition of road traffic since 1980. It includes Weigh in Motion (WiM) sensors which record data on individual axle weights as vehicles travel over them at highway speeds. The NTDS automatically validates collected data using a configurable, data-driven, rule-based engine.

The NTDS contains automated data handling (collection, validation, flagging, patching, processing, storage and output) wherever possible. Based on an open architecture, the NTDS includes automated interfaces for the upload and download of data to and from other systems. A web based public portal of the NTDS is being made available, which will be automatically updated on a daily basis.

Figure 3.1.19. NTDS Public portal (source: Transport Scotland)

3.1.5. NETHERLANDS TRAFFIC MANAGEMENT CENTRES

The Netherlands has 5 regional and one national traffic control centre. Here are the major facts about traffic management systems in the Netherlands:

- Motorway Traffic Management System: 2675 km carriageway
- Monitoring with loop detectors: extra 1362 km carriageway
- Dynamic route information (VMS): 115 (text) + 297 (graphical)
- Ramp metering systems: 122
- Traffic signal control systems: 165 (in total ±5600 in NL)
- Hard shoulder running: 180 km
- Dynamic left lane: 158 km
- Lanes for trucks or busses: 337 km

The most relevant automated functions are presented below.

3.1.5.1. END OF QUEUE WARNING

This system utilizes flashing lights and variable speed limit signs to alert drivers for the end of a queue and recurrent congestion as shown in Figure 3.1.20. The function is automated and based on field data, is initiated automatically based on an assessment algorithm, requiring no intervention by an operator. It is also used to warn for lane closures and incidents.

Figure 3.1.20. Example of End of que warning implementation (source: RWS)

3.1.5.2. DYNAMIC SPEED LIMITS

Dynamic speed limits take into account real time traffic, road and weather conditions and better reflect the safe speed. The function is automated and based on field data, is initiated automatically based on an assessment algorithm, requiring no intervention by an operator.

3.1.5.3. (TRUCK) HEIGHT WARNING

The warning system comprises a vehicle-height measurement sensor, a camera, and roadside dynamic route information panels (DRIP) as shown in Figure 3.1.21. Some systems are also capable of displaying a photograph. If the height measurement sensor is triggered by a vehicle, it sends a signal to the camera, which then takes a picture of the vehicle. The photo is sent to the DRIP and is then displayed on the sign's screen, together with a request to take the next exit.

Figure 3.1.21. Example of (Truck) height warning (source: RWS)

European ITS Platform

3.1.5.4. RAMP METERING

Ramp metering is the control of a traffic stream from an on-ramp to the motorway. This is done using special traffic lights that allow vehicles to enter the motorway one by one. The function is automated and based on field data, is initiated automatically based on an assessment algorithm, requiring no intervention by an operator.

3.1.5.5. JOURNEY TIME INFORMATION

Predicted travel times for alternative routes are displayed on a VMS as shown in Figure 3.1.22. This function is automated and based on field data from loop detectors and uses and assessment algorithm, requiring no intervention by an operator.

Figure 3.1.22. Example of journey time information (source: RWS)

3.1.5.6. TRAFFIC FLOW INFORMATION

The current status of the traffic flow on (mainly) ring roads is displayed in order to provide road users more in depth information to choose his route (example in Figure 3.1.23). This function is automated and based on field data from loop detectors and uses and assessment algorithm, requiring no intervention by an operator.

Figure 3.1.23. Example of traffic flow information (source: RWS)

3.1.5.7. HARD SHOULDER RUNNING

This function ensures temporary use of the hard shoulder during peak hours. Matrix signs on gantries are used to indicated whether the lane is open (green arrow) or closed (red cross) as shown in Figure 3.1.24. Opening and closing is done manually for safety reasons, an operator visually inspects the lane using cameras. Managing the lanes (including accompanying speed limits) and incident detection during operation is automated.

Figure 3.1.24. Example of hard shoulder running (source: RWS)

3.2. Sensors and data collection

This chapter briefly presents the main sensors need for the management centres to perform their functions. A more detailed description of the sensors and examples of technical specifications can be found in Annex 1.

3.2.1. TRAFFIC SENSORS

3.2.1.1. INTRUSIVE TRAFFIC SENSORS

A sensor will be intrusive when its location is directly on the road, i.e. in contact with the ground.

In terms of installation and maintenance, they are complex and costly due to the disruption on the road traffic. Moreover, they are more likely to cause damage to vehicles.

3.2.1.1.1 INDUCTIVE LOOPS

Inductive loops consist of isolated electrical cables which can take different configurations: square, rectangular, diamond shaped, circular or octagonal. Its operation is based on impedance variation recorded in the loop to the passage of a vehicle.

Inductive loops provide much information about the condition prevalent of traffic, including flow, occupancy, type of vehicles and speed. It is necessary to have double loops to measure the speed of a car.

Accuracy of the system depends largely on the process installation and calibration. Loop detectors are always limited by their inability to detect stationary vehicles. Inductive loops may be used alone, or can be incorporated with other traffic systems to provide information regarding vehicle presence.

A good detection system is maintained within an accuracy of 5%. The effectiveness of management strategies such as incident detection depends on the reliability and accuracy

of loop detectors. Some configurations of loop detectors provide different electromagnetic fields which can affect the detection of vehicles in adjacent lanes.

Sensors are unreliable due to their large number of faults (faults of 0.13 to 0.29 per turn and year), affecting up to 50% of these sensors in a single year. The margin of error can be quantified on average to the following percentages: 5% in volume, 10% in speed and classification.[5]

3.2.1.1.2 *MAGNETIC FIELD TRAFFIC SENSORS*

Magnetic sensors are passive devices that detect the presence of a ferrous metal object through the perturbation (known as a magnetic anomaly) metal causes in the Earth's magnetic field.

One advantage over inductive loops is that the magnetic field sensors can be used in parking, since the latest versions can detect the presence of vehicles.

Figure 3.2.1. Example of magnetic detector (source: DGT)

3.2.1.1.3 *PNEUMATIC ROAD TUBES*

This sensor consists of a detector rubber shaped closed tube placed transversely to the carriageway. At the other end, the tube terminates in a flexible metal membrane. When passing over, the wheels of the vehicles increase the air pressure inside, moving the metal membrane which closes an electrical contact.

This type of detector is very useful in temporary or short-term installations, since the rubber tubes are easily placed on the roadway and the counter is powered by a battery.

Placing two tubes at a short distance, it is possible to calculate the vehicle speed (double pneumatic road tube).

3.2.1.1.4 *PIEZOELECTRIC SENSORS*

Detection is based on the pressure generated by the vehicle passing over piezoelectric sensors. It detects the passage of the vehicle based on the electric charge generated in the piezoelectric material when depressed by a vehicle. The electrical signal is transmitted to a counter or to a computer with software suitable for processing.

3.2.1.1.5 *FIBRE OPTIC SENSORS*

Fibre optic traffic sensors are best suited for axle detection. They work for any speed, in any pavement with the highest accuracy and outstanding durability.

This system is based on the change in the optical signal parameters due to optic fibre strain under the weight of a passing transport vehicle. When a vehicle passes over the detector, a decrease in optical transmittance is produced. This variation is interpreted by an

[5] Fusión de datos para la obtención de tiempos de viaje en carretera. David Abeijón, Francesc Soriguera and Leif Thorson. June 2007.

optoelectronic interface that determines the presence of a vehicle and even the type of vehicle in question.

They need LED power to operate properly whereas they do not pick up any energy from the road which makes them insensitive to any road vibrations. Because they are not metallic, they are immune to radio frequency and magnetic fields.

Figure 3.2.2. Example of fibre optic sensor (source: DGT)

3.2.1.2. NON-INTRUSIVE TRAFFIC SENSORS

Unlike intrusive sensors, these detectors do not directly affect traffic during operation, as they are placed in overhead or lateral position on the road without coming into contact with the road. Generally used for location or existing infrastructure (bridges over the track, signalling panels porches or tolls), own porches or posts.

3.2.1.2.1 MICROWAVE RADAR SENSORS

Two types of microwave radar sensors are used in roadside applications: those that transmit continuous wave (CW) Doppler waveforms and those that transmit frequency modulated continuous waves (FMCW). The traffic data they receive are dependent on the respective shape of the transmitted waveform.

Microwave radar sensors may be mounted over the middle of a lane to measure approaching or departing traffic flow parameters in a single lane or at the side of a roadway to measure traffic parameters across several lanes.

Forward-looking, wide beamwidth radars gather data representative of traffic flow in one direction over multiple lanes. Forward-looking, narrow beamwidth radars monitor a single lane of traffic flowing in one direction. Side-mounted, multiple detection zone radars project their detection area (e.g. footprint) perpendicular to the traffic flow direction. These sensors provide data corresponding to several lanes of traffic, but generally not as accurately as the same radar mounted in the forward-looking direction can do. Side-mounted, single-detection zone radars are typically used to detect vehicle presence in one or more lanes at signalized intersections.

Figure 3.2.3. TC-20 Doppler microwave radar (source: DGT)

3.2.1.2.2 *INFRARED SENSORS*

Active and passive infrared sensors are manufactured for traffic management applications. Active infrared sensors illuminate detection zones with low-power infrared energy transmitted by laser diodes operating in the near infrared region of the electromagnetic spectrum at 0.85 µm. A portion of the transmitted energy is reflected or scattered by vehicles back toward the sensor.

Passive sensors transmit no energy of their own. Rather, they detect energy from two sources: energy emitted from vehicles, road surfaces and other objects in their field of view and energy emitted by the atmosphere and sun that is reflected by vehicles, road surfaces, and other objects into the sensor aperture.

The energy captured by active and passive infrared sensors is focused by an optical system onto an infrared-sensitive material mounted at the focal plane of the optics. With infrared sensors, the word detector takes on another meaning – namely, the infrared-sensitive element that converts the reflected and emitted energy into electrical signals.

Real-time signal processing is used to analyse the received signals for the presence of a vehicle. The sensors are mounted overhead to view approaching or departing traffic. They can also be mounted in a side-looking configuration. Infrared sensors are utilized for signal control; volume, speed, and class measurement; detection of pedestrian in crosswalks; and transmission of traffic information to motorists.

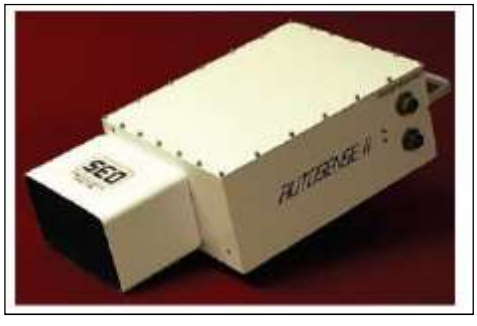

Figure 3.2.4. Autosense II laser radar sensor (source: DGT)

3.2.1.2.3 *ULTRASONIC SENSORS*

Ultrasonic sensors transmit pressure waves of sound energy at a frequency between 25 and 50 kHz, which are above the human audible range.

Pulse-shape waveforms measure distances to the road surface and vehicle surface by detecting the portion of the transmitted energy that is reflected towards the sensor from an area defined by the transmitter's beamwidth. When a distance other than that to the background road surface is measured, the sensor interprets that measurement as the presence of a vehicle. The received ultrasonic energy is converted into electrical energy. This energy is then analysed by signal processing electronics that is either collocated with the transducer or placed in a roadside controller.

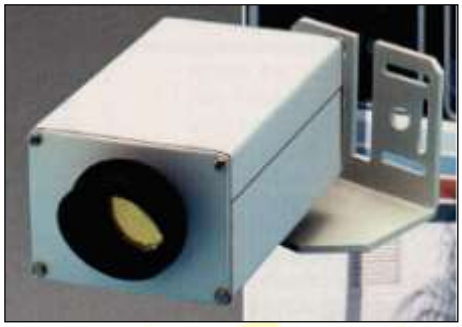

Figure 3.2.5. TC-30C ultrasonic range-measuring sensor (source: DGT)

3.2.1.2.4 PASSIVE ACOUSTIC SENSOR

This system is based on detecting acoustic energy or audible sounds produced by vehicular traffic from a variety of sources within each vehicle and from the interaction of vehicle's tires with the road. When a vehicle passes through the detection zone, an increase in sound energy is recognized by the signal processing algorithm and a vehicle presence signal is generated. When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold, and the vehicle presence signal is terminated. Sounds from locations outside the detection zone are attenuated.

Single lane and multiple lane models of acoustic sensors are marketed. Both use a two-dimensional array of microphones to detect the sounds produced by approaching vehicles.

3.2.1.2.5 LICENSE PLATE RECOGNITION

An Automatic License Plate Reader (ALPR) is an image-processing technology used to identify vehicles by their license plates. It is a special form of OCR (Optical Character Recognition) where algorithms are employed to transform the pixels of the digital image into the text of the number plate.

The system uses illumination (such as Infra-Red) and a camera to take the image of the front or rear of the vehicle, then image-processing software analyses the images and extracts the plate information.

The significant advantage of the LPR system is that it can keep an image record of the vehicle which is useful in order to fight crime and fraud. An additional camera can focus on the driver face and save the image for security reasons. Additionally, this technology does not need any installation per car.

3.2.1.2.6 AUTOMATIC INCIDENT DETECTION

Automatic Incident Detection (AID) is based on video analytics technologies, applied to automatic real time detection of traffic incidents on roadways (example in Figure 3.2.6). It uses images from CCTV video cameras. Those images are processed either by a detection platform called Analyser or directly within the traffic sensor or the smart camera. The video

analytic technologies automatically select pertinent information, such as incident and traffic data.

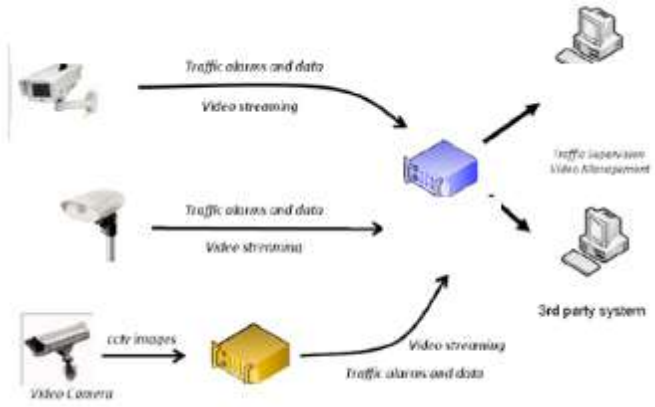

Figure 3.2.6.Typical AID configuration (source: DGT)

AID provides traffic operators with alarms seconds after an event has occurred, even before consequences of the incident can be noticed by the operator or any traditional loop-based detection system. The AID algorithm extracts information on objects from a number of video images within a monitored area.

3.2.2. FLOATING CAR DATA (FCD)

Floating Car Data (FCD) is emerging as a means of monitoring traffic without the need for deploying and maintaining equipment in the right-of-way. In contrast to speed sensors, vehicle probes directly measure travel time using data from a portion of the vehicle stream. Commercial vehicle probe data services primarily include the use of cell phones and automated vehicle location (AVL) data.

Adoption of such technologies is being driven by the high cost of deploying and maintaining fixed-sensor networks, including loop or radar-based detection. Concurrently, demand for comprehensive traffic monitoring is growing, both from travellers, who need accurate, real-time data, and transportation agencies, which need to assess the performance of the system as a whole.

The cost for gathering traffic data, either from probe-based or traditional speed sensors, is declining due to both the proliferation of technology and the emergence of businesses dedicated to traffic data collection and dissemination. Traffic data collection within a transportation agency has traditionally been application-specific and geographically constrained, such as with the need to actuate a traffic signal or collect speed and count data for planning purposes. This “stovepipe” method is being replaced by comprehensive traffic monitoring across the entire roadway system. Such an approach feeds not only legacy applications, but also supports the growing demand for advanced traveller information services (ATIS) data, such as travel time and congestion reports, and performance measurement data that assesses and improves the efficiency of existing highway operations.

3.2.3. METEOROLOGICAL SENSORS

In addition to traffic sensors, there are other important sensors for ITS systems: meteorological and environmental sensors to measure weather (fog, wind, snow, ice, rain, wind) and conditions which may affect driving conditions (visibility, pavement temperature, road conditions, etc.).

Meteorological sensors are usually installed at points of high frequency road weather incidents.

3.2.3.1. TEMPERATURE SENSORS

The temperature sensors are devices that convert temperature changes into electrical signals changes that are processed by electric or electronic equipment. There are three types of temperature sensors: thermistors, RTDs and thermocouples.

For correct temperature measurement the sensor must be protected from direct exposure to sunlight and rainfall, as well as adequately ventilated. Routinely, the surface temperature is measured two meters from the ground.

3.2.3.2. WIND SENSORS

There are two types of wind sensors: those that measure the intensity and those which measure wind directions. There are also solutions in which both sensors are included in the same assembly.

3.2.3.3. ATMOSPHERIC PRESSURE SENSOR

Atmospheric pressure is the pressure exerted by the air at any point of the atmosphere. Usually it refers to the earth's atmospheric pressure. Pressure measurement International System of Units is the Newton per square meter (N /m^2) or Pascal (Pa).

The actual barometers are designed to make accurate pressure measurements in a number of environmental conditions. Using capacitive, absolute pressure sensor technology, some trademarks achieve excellent hysteresis as well as outstanding long-term stability.

3.2.3.4. HUMIDITY SENSORS

The humidity is the ratio of water vapour present in the air, and that is how the measure is provided, in percent. Typically, this ratio varies inversely with the change in air temperature, so the highest relative humidity is given in lower temperatures. Normally, after dawn, when the air is heated, the relative humidity decreases. In the case of water vapour in air at 100% relative humidity is considered the case of the concentration of water vapour saturation.

3.2.4. ENVIRONMENTAL SENSORS

The environmental sensors allow measuring additional parameters to atmospheric parameters measured by meteorological sensors, important to know the state of the road and driving conditions, such as:

- Visibility.
- Temperature highway pavement.
- State of the road if it is wet or dry.
- Chemical analysis pavement.

3.2.4.1. VISIBILITY SENSORS

Visibility sensors measure optically atmospheric visibility, also known as Meteorological Optical Range (MOR), which is the greatest distance at which a large dark object (which subtends an angle of > 0.5 degrees) can be seen and recognized against a background of clear sky.

Human ability to see long distance is altered by what is known as obstruction of vision: rain, snow, fog, pollen, smoke, etc. As light propagates through the atmosphere, it is attenuated by absorption and scattering of these obstructing vision.

Visibility sensors use the principle of forward scattering. The optical system is designed so that the projected infrared light from the transmitter (TX) intersects the field of view of the receiver (RX) with a front angle. The intersection area is known as the sample volume. The signal strength received at the receiver is inversely proportional to the visibility.

3.2.4.2. LUMINANCE METER

The amount of light on a highway has significant influence on the quality of driving of drivers, as well as their safety. This is especially important in tunnels.

How well the eye recognises vehicles and other obstacles in a tunnel depends on the lighting and visibility as well as the reflexion characteristics of the road surface and the tunnel walls. Tunnel lighting needs to be adapted to these environmental conditions.

Luminance is the measure representing what a human being perceives as brightness and as such is the main control variable for the tunnel lighting.

The luminance photometer comes with a zoom lens that is focussed to measure the relevant area. Light from this area through the lens is directed to the photo element detecting its intensity. The integrated evaluation unit then calculates the luminance and provides it through the analogue output(s).

3.2.4.3. ROAD GENERAL CONDITIONS SENSOR

This type of sensor uses various technologies (fibre, carbon fibre electrocardiograms) for a series of measurements to measure the state of the road being analysed.

Among the measures obtained are the following:

- Detection of possible coating of the surface (water, snow, etc.).
- Conductivity and surface temperature.
- Subsurface temperature.

Some road sensors contain facilities to optically determine the pavement surface coverage. This will result in a measured value for water thickness in wet conditions and reliable ice and snow coverage detection.

The electrical conductivity and electrochemical polarizability measurements are important in determining the amount of de-icing chemical on the pavement surface. Together with the temperature and measurement of waterfilm thickness the sensor accurately determines the freezing temperature and the risk of ice formation.

Conductivity disappears for mono-crystalline ice (black ice). Therefore, the sensor features an integrated black ice detector which measures the characteristic capacitance of the pavement surface.

3.3. Data processing and analytics

3.3.1. SPANISH TRAFFIC MANAGEMENT CENTRES

3.3.1.1. JOURNEY TIME INFORMATION

This system at the Southwest Traffic Management Centre is based on a number of cameras with License Plate Recognitions (LPR) distributed on different monitored roads. These cameras register vehicle licence plates and they send this information to a TMC which compares the data (coincidence between license plates received from different control points) and calculates average travel times among different points of the system.

The equipment and elements that take part in this system are:

- LPRs
- Image pre-processing unit
- Recognition of license plates unit
- Column for cameras
- Communication equipment
- Informative panels
- Processing centre equipment
- Administration software and system operation

The results of the calculations will be shown on assigned VMS. Travel times do not have their own priority on VMS, the importance of the message will depend on the priority fixed in the specific panel.

The signalization of travel times will be updated every minute, as well as their behaviour.

It is possible to filter information like:

- Historical messages
- Historical routes
- Historical sections

Visualizing panel messages

In the filtering section, it is possible to choose different criteria like:

- Panel: it is possible to introduce the name of a determined panel and the system will show the filtered data.
- PK: the system will show the panels containing the number of the kilometre point which has been introduced.
- Road: it is possible to select the road where the panel is located.

- Direction: the direction associated to the panel can be selected also in the filtering zone.

The application also allows to display the information of only one panel.

To apply configuration changes, it is necessary to click on the update button. The export button provides data in a file compatible to the software Microsoft Excel.

Figure 3.3.1. Panel messages dialog (source: DGT, Southwest TMC)

European ITS Platform

As shown in Figure 3.3.1, the interface for the application related to the data list contains the following information:

- Title: the window title reflects the date of the information requested.
- Name of the panel: identifying code of the panel.
- Alternation: shows if the panel has multiple concurrent messages.
- Route: associated with the reference of the line.
- Destination: destination control point of the given route.
- Message: text shown by the line of the panel.
- Active: indicates if the panel or the route is operative or not. It is possible to press the button and modify the field from active to inactive, introducing a text message explaining the reason of the changes.

- Motive: indicates the reason of the deactivation of panels or routes.
- Valid: reflects if the time calculated is right or not. In case of being wrong, positioning the mouse over the icon, the filters that have failed the route will be shown.
- Duration: associated with the time in seconds estimated for the route.

Visualizing historical messages

The tool also allows to see historical messages of a specific panel for a selected period.

The fields included in the filtering zone of historical messages are:

- PK: the system will show the panels containing the number of the kilometre point which has been introduced.
- Road: it is possible to select the road where the panel is located.
- Direction: the direction associated to the panel can be selected also in the filtering zone.

Once the filter is selected, the list of the selectable panels will be updated in consequence. It is necessary to select a panel to obtain the desired information.

The export button provides data in a file compatible to the software Microsoft Excel and the Graffic button downloads a graphic in Excel.

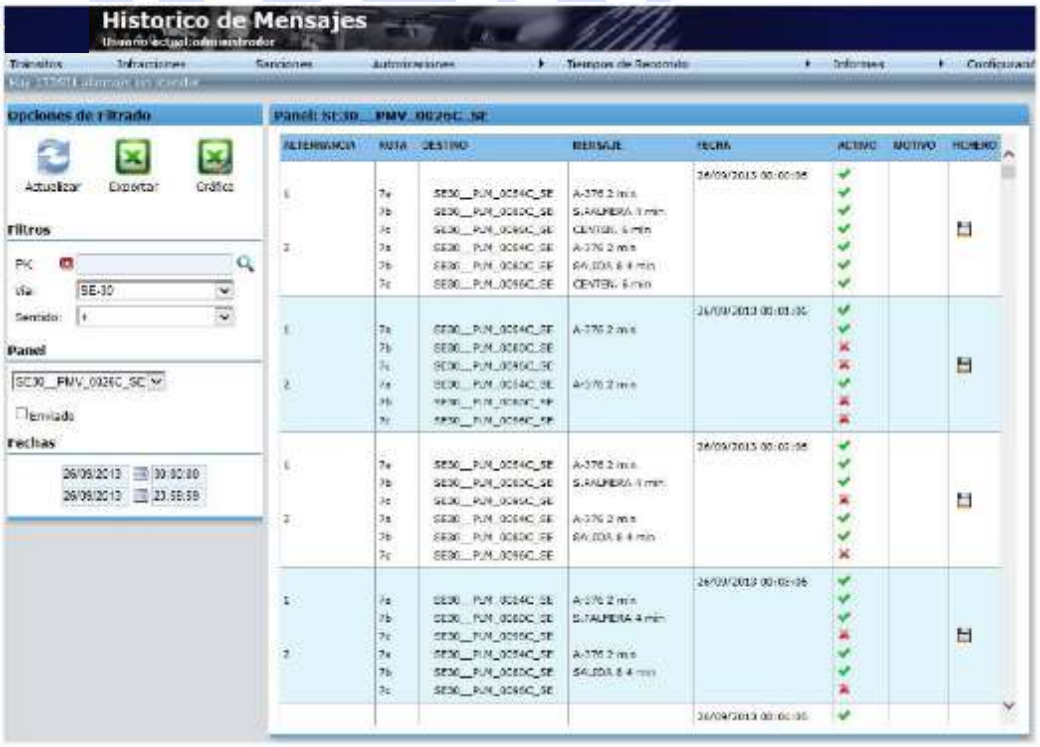

Figure 3.3.2. Historical messages dialog (source: DGT, Southwest TMC)

The list section contains the following information (Figure 3.3.2):

- Alternation: shows if the panel has multiple concurrent messages.
- Route: associated with the reference of the line.
- Destination: destination control point of the given route.
- Message: text shown by the line of the panel.
- Date: day an hour of the signalization.
- Active: indicates if the panel or the route is operative or not. It is possible to press the button and modify the field from active to inactive, introducing a text message explaining the reason of the changes.
- Motive: indicates the reason of the deactivation of panels or routes.
- Valid: reflects if the time calculated is right or not. In case of being wrong, positioning the mouse over the icon, the filters that have failed the route will be shown.
- File: allows the download.

Visualizing historical routes

In this screen it is possible to obtain route time calculations for a selected period of time.

A route must be selected in order to present data. The filtering zone eases the search of the route allowing to choose an origin and a destination.

For the origin point it is possible to filter by:

- PK: the system will show the panels containing the number of the kilometre point which has been introduced.
- Road: it is possible to select the road where the panel is located.
- Direction: the direction associated to the panel can be selected also in the filtering zone.

Once the filter is selected, the list of the selectable origins and routes will be updated in consequence. If an origin is selected, all the destination and routes with this origin will be shown, and once the destination is selected, the system will choose automatically the route.

Figure 3.3.3. Historical routes dialog (source: DGT, Southwest TMC)

The list section contains the following information (Figure 3.3.3):

- Title: the window title reflects the route visualized.
- Date: the day and hour of the submitted data.
- Travel time: duration of the ride in seconds.
- Speed: calculated speed in km/h.
- Active: indicates if the panel or the route is operative or not.
- Valid: reflects if the time calculated is right or not. In case of being wrong, positioning the mouse over the icon, the filters that have failed the route will be shown.

Visualizing historical sections

In this screen it is possible to obtain section time calculations for a selected period of time.

The filtering zone eases the search of the route allowing to choose an origin and a destination.

For the origin point it is possible to filter by:

- PK: the system will show the panels containing the number of the kilometre point which has been introduced.
- Road: it is possible to select the road where the panel is located.
- Direction: the direction associated to the panel can be selected also in the filtering zone.

Once the filter is selected, the list of the selectable origins and routes will be updated in consequence. If an origin is selected, all the destinations and routes with this origin will be shown, and once the destination is selected, the system will choose automatically the route.

Figure 3.3.4. Historical section dialog (source: DGT, Southwest TMC)

The list section contains the following information (Figure 3.3.4):

- Title: the window title reflects the section visualized.
- Date: the day and hour of the submitted data.
- Travel time: duration of the ride in seconds.
- #Valid: number of valid coincidences.
- #Total: total of coincidences.
- Speed: calculated speed in km/h.
- Active: indicates if the panel or the route is operative or not.
- Valid: reflects if the time calculated is right or not. In case of being wrong, positioning the mouse over the icon, the filters that have failed the route will be shown.

3.3.1.2. AUTOMATIC SYSTEM FOR AVOIDING REAR END COLLISIONS

In the Northwest Traffic Management Centre there is an automatic system for avoiding rear end collisions implemented on the AG-64 highway.

The objective of the system is the improvement of the safety by the signalization of possible impacts, speed excesses or accidents.

In this particular case, a specific application has been developed under the name of “ISIS”. The main screen of the application is shown in Figure 3.3.5. This tool analyses the routes, divides them in different sections, calculates the decelerations and compares all this data of different vehicles with an algorithm. Depending on the situation, the application will activate or not the signalling on the section.

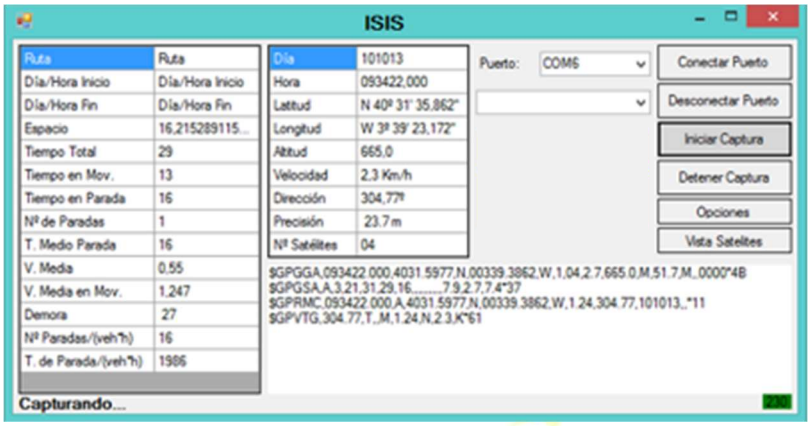

Figure 3.3.5. ISIS main screen (source: DGT, Northwest TMC)

The algorithm analyses vehicles in real time calculating the hour of entrance and exit of the section, taking into account different parameters:

- Constant speed vs Uniform decelerated speed.
- Heavy vehicle vs Light vehicle.
- Heavy loaded vehicle vs Empty heavy vehicle.

Using all this information, the algorithm estimates and makes prognosis of possible impacts.

Depending on the speed analysis the signalling will vary as following:

- Possible impact

- Possible impact between heavy vehicles

- Speed excess

In the Southwest Traffic Management Centre there is a pilot programme related to safety distance and signalling on VMS.

An application calculates every 15 minutes, automatically, the distance between vehicles on the road A-497 in the following kilometre points:

- A-497 4+300 D
- A-497 6+100 D
- A-497 16+500 D

If this distance is lower than the limit established by DGT, an alert will be shown and it will be possible to signalize on the VMS the kilometre point of the infringement.

The protocol proceeds as follow:

- For each 15 minutes, the safety distance will be calculated for each section, using the formula:

$$d_{seguridad} = \frac{V^2}{100}$$

where:

dseguridad: safety distance for each section in metres.

V: average speed in the section for the 15 minutes in km/h, calculated as the weighted average of the average speeds of each lane for those 15 minutes.

- Average distance will be also calculated every 15 minutes for each section as the weighted average of the average distance of each lane.
- For each section and every 15 minutes, average distance will be compared to safety distance.

In case of being lower the average distance in more than a 10% than the safety distance calculated, a message will be sent. In other words, the alert will be shown when:

$$d_{media} < \frac{90 * d_{seguridad}}{100}$$

The application without alarms will show the kilometre points in colour green as can be seen in Figure 3.3.6

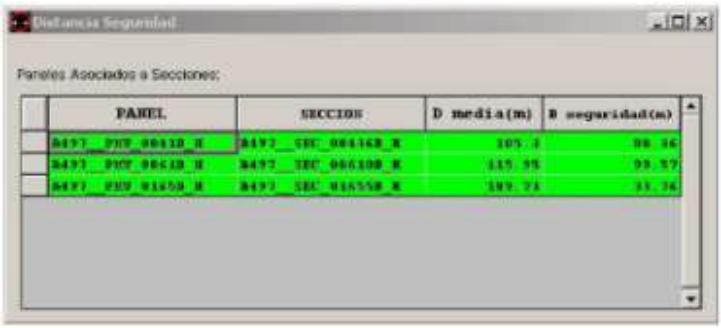

Figure 3.3.6. Safety distance dialog (source: DGT, Southwest TMC)

If there is an infringement, the safety distance will be shown in colour red and a message will pop up asking for the acceptance to signalize automatically the warning as can be seen in Figure 3.3.7.

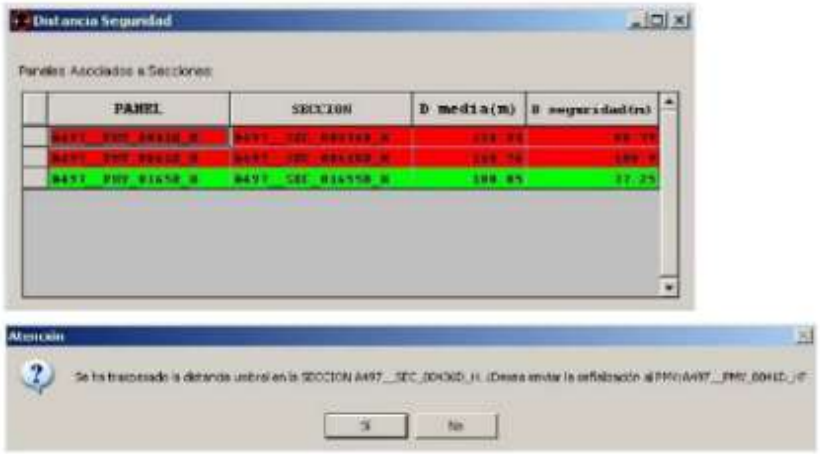

Figure 3.3.7. Safety distance warning dialog (source: DGT, Southwest TMC)

Once the point meets the required safety distance, a new message will pop up asking for changing the VMS.

In case of accepting the signalling of the application, the VMS will display the alternation shown in Figure 3.3.8.

Figure 3.3.8. VMS message for drivers (source: DGT, Southwest TMC)

3.3.2. T-LOIK IN FINLAND

In Finland, data processing and analytics have been the focus when developing the new traffic centre operator decision support system and user interface, T-LOIK, taken into use in 2015 within the NEXT-ITS corridor project.

The major technical solutions are based on off the shelf software components, using as much of open source as possible. The integration of the existing legacy systems to T-LOIK has been carried out by developing as generic interfaces to services as possible. A major effort has been put into developing a uniform system and data architecture which enables transport system and traffic information integration. This modular architecture developed supports the later integration of traffic systems and traffic data. Thus the base system allows the gradual implementation and quality control of new sources of traffic data, data fusion, data analysis, alerts and automation. These are crucial for the deployment of ITS Directive's priority actions.

Figure 3.3.9 below shows a screenshot of the T-LOIK common user interface and an integration layer that integrates a number of data sources and information.

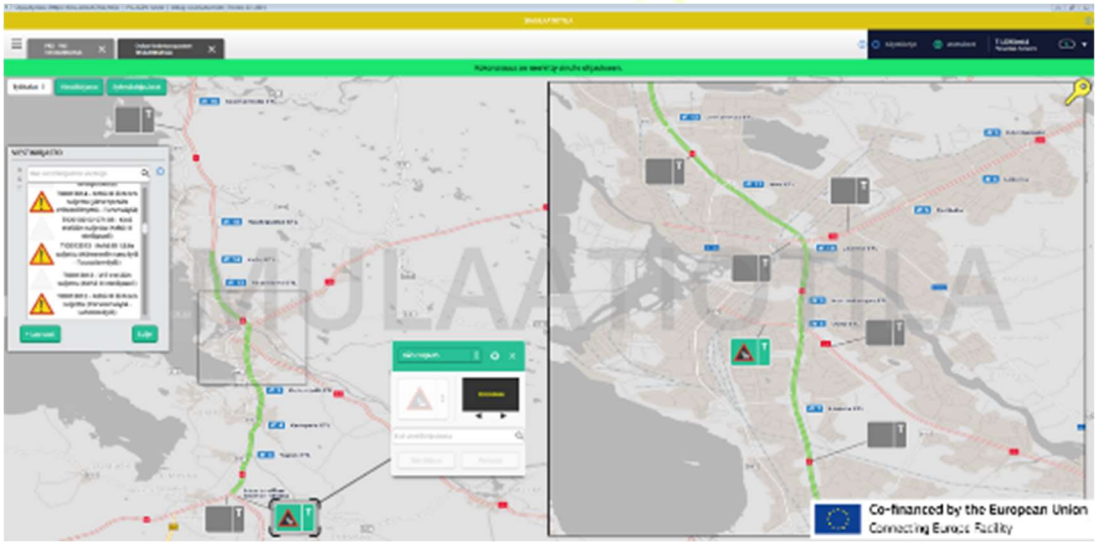

Figure 3.3.9. Screenshot of the T-LOIK common user interface (source: FTA)

3.3.3. TRAFFIC SCOTLAND SYSTEMS

3.3.3.1. TRAFFIC MONITORING

The most basic function of the Incident Management System (IMS) is to detect incidents through automated traffic monitoring. Traffic Monitoring involves the gathering of and assessing of traffic data. Detector sites in the road detect the arrival and departure of vehicles and, from this basic presence information, the following traffic flow information is derived for each lane and for the whole carriageway at a traffic monitoring site:

- Traffic Volume (Flow)
- Average Speed

- Occupancy
- Flow Classification in terms of vehicle length.

Within the IMS traffic flow is classified into short, medium and long vehicles, with the total flow for the lane being derivable by summing those numbers. This feed of information provides Operators and Web users with information on the state of the road network including congestion, Journey Time and the location and extent of Queues. Data is collected from loop detectors as shown in Figure 3.3.10**Virhe. Viitteen lähdettä ei löytynyt.**.

In addition to inductive loops, dual zone infrared sensors and radar units have been configured to provide inputs to the Traffic Monitoring Units (TMU) illustrated below in Figure 3.3.10**Virhe. Viitteen lähdettä ei löytynyt.**. A combination of RS485 HDLC link to a Multi-Purpose Controller (MPC), or via a RS232 link and Packet Radio communications, or UTMC based IP communications are used to connect the TMUs back to the IMS.

The following types of data are automatically collected for each site either on a whole site basis or for each individual lane:

- Hourly and 15 minute data, transferred to the IMS Instation everyday
- 3 minutes data provided continuously
- Vehicle by Vehicle data (transferred on a daily basis as required).

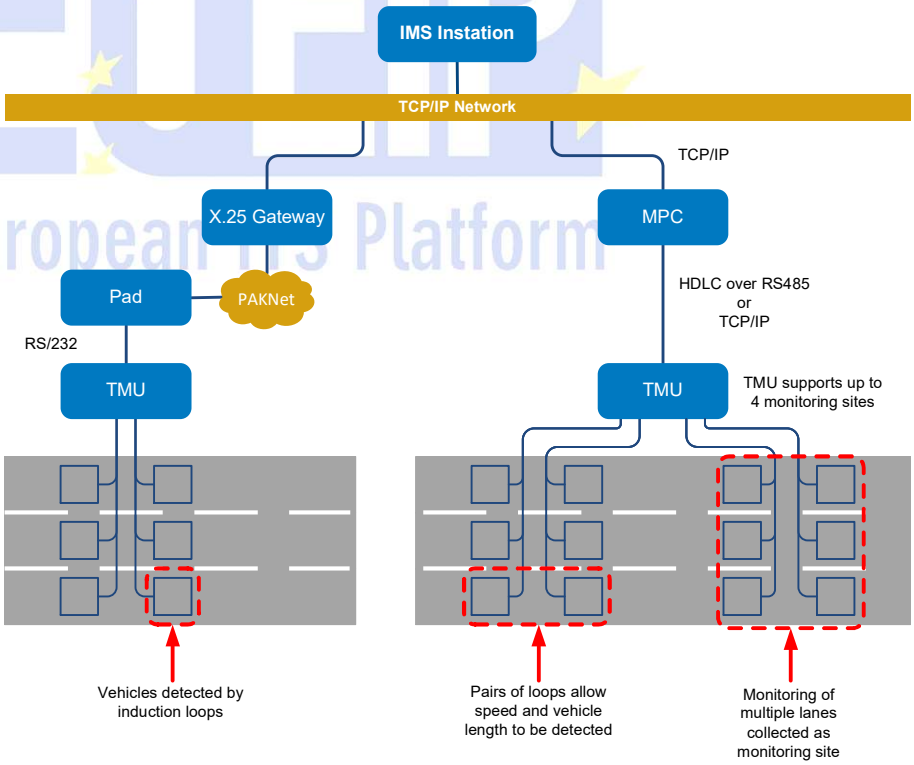

Figure 3.3.10. Example traffic monitoring architecture (source: Transport Scotland)

3.3.3.2. *INCIDENT DETECTION*

To support the automated operation of incident detection algorithms, the TMU is capable of acquiring data at much faster intervals, typically 10 seconds. This is known as LVDS (Logical Vehicle Detection Station) data. If an LVDS is configured the data is transferred to the MPC and is used in the MPC to support the following:

- McMaster Queue Transient detection
- APID (All Purpose Incident Detection)
- Ramp Metering
- Variable Mandatory Speed Limits (VMSL) – Flow/ Speed band calculation
- Refuge Monitoring – Detection of vehicles in a refuge

LVDS data supports the operation of algorithms in the MPC that require flow, speed and occupancy data at fast intervals, the data is not normally used outside the MPC.

3.3.3.3. *ROUTE TRAVEL TIMES*

The IMS automatically calculates travel time for routes based on speed and flow data from the monitoring sites. Routes are formed by a set of contiguous monitoring sites. The basic calculation uses speed from each monitoring site to calculate travel time for each section of road and then sums the section travel times to form a route travel time. This works well in free flow conditions; however, where traffic conditions are breaking down, the algorithm can also use flow data to estimate travel time. The Route Travel Time window, Figure 3.3.11, allows the calculation of travel time for routes to be monitored.

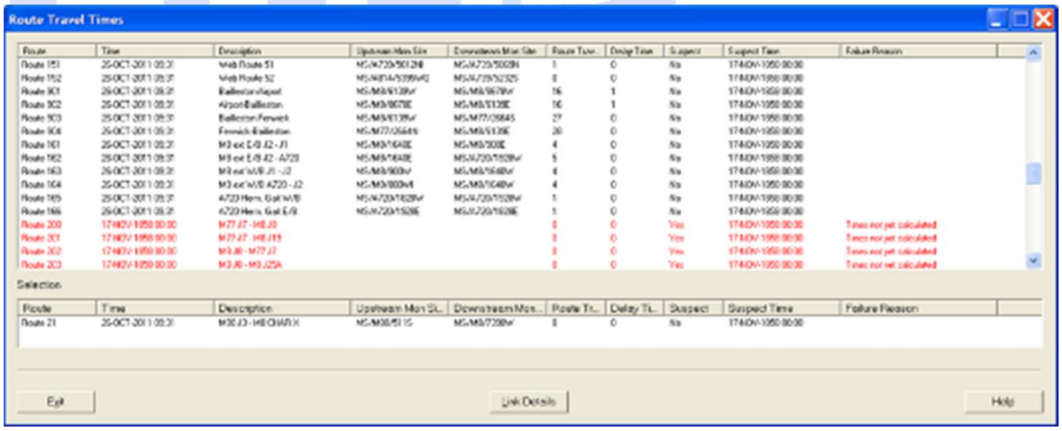

Figure 3.3.11. Route Travel Times window (source: Transport Scotland, IMS)

In addition to the calculation of Travel Times from monitoring site data, the system also receives route travel time data from other sources:

- Directly from separate ANPR detection systems connected to MPCs; and
- From the Journey Time System (JTS) (Data Fusion) which collates, merges and cleanses all travel time information available to the system flexibility from a variety of internal and external sources, including both ANPR and Bluetooth derived journey times.

The system consolidates this information to support the display of route travel time and delay information on VMS. The Response Handling system integrates route travel times into VMS displays using plans, manual settings and a Traffic Information Timetable using:

- Dynamic automatically updated variable elements embedded into VMS legends
- Specialised Local Journey Time Signs (LJTS) configured to display travel time information on key routes

The system also transfers route travel times to the Data Fusion system for integration with other sources of travel time to provide journey time information on the Traffic Scotland web site information feeds that users can subscribe to.

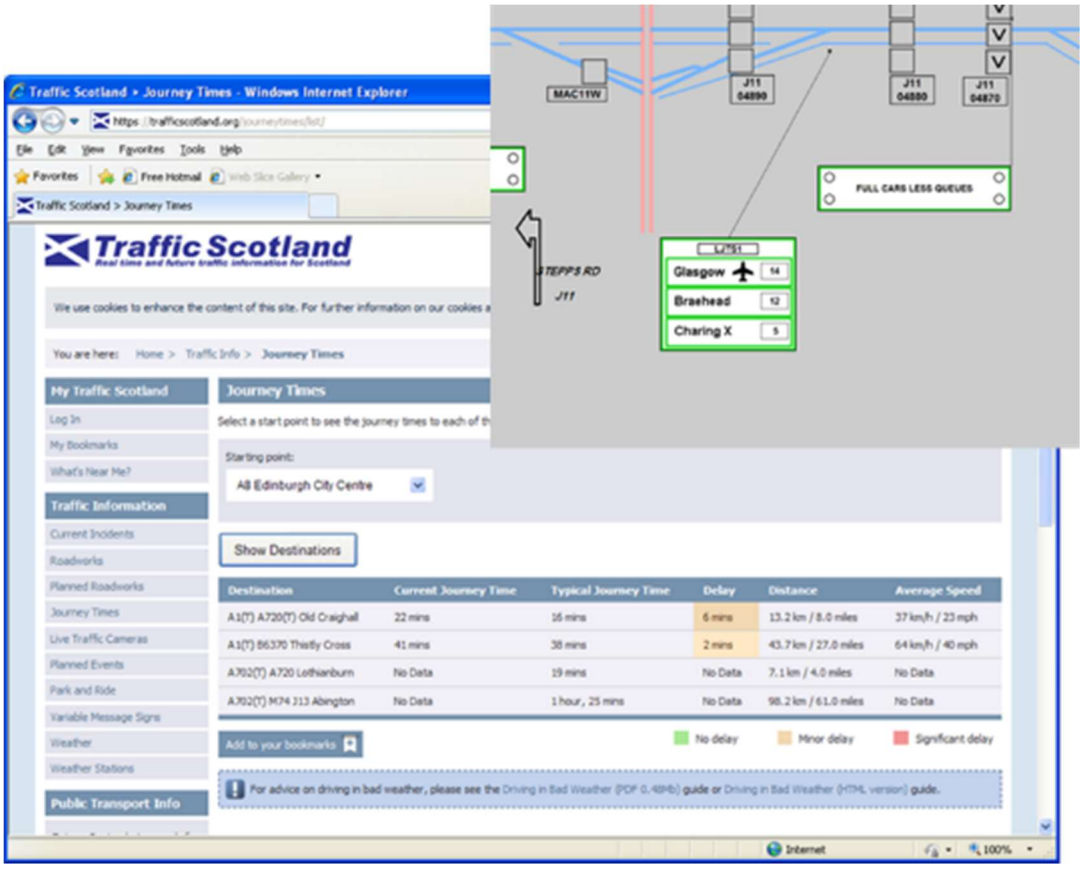

Figure 3.3.12. Route specific travel times on web site and IMS GUI (source: Transport Scotland, Website and IMS)

3.3.3.4. CONGESTION LEVELS

The IMS utilises traffic data to automatically generate a Congestion Layer, displaying a colour-coded representation of the road network's congestion state. These congestion states are roughly equivalent to the 'Level of Service' (LOS) conditions defined in the Highway Capacity Manual (Transport Research Board, Washington DC, 2000).

There are three states:

- 1. Good conditions shown as Green (covering LOS A, B and C)
- 2. Deteriorating conditions are shown as Orange (covering LOS D and E)
- 3. Poor conditions (traffic flow broken down) are shown as Red (covering LOS F)

The congestion state is calculated on a site or lane basis for each monitoring site, and is associated with road network links and segments for display on the GUI map. Where no data is available the road state is not known so the congestion layer for that section of road is not coloured. As shown in Figure 3.3.13, the calculation of congestion level is based on configurable flow/speed thresholds.

Flow Threshold	2	Bad	Deteriorating	Deteriorating
	1	Bad	Deteriorating	Good
	0	Bad	Good	Good
Congestion Level		0	1	2
		Speed Threshold		

Figure 3.3.13. Congestion Thresholds (source: Transport Scotland)

The road congestion state of each link is also transferred to the Traffic Scotland website to support the delivery of the public website view of road network conditions.

Traffic data profiling is used to build up a picture of typical traffic conditions which assists Operators in identifying abnormal events affecting the road network, for example accidents, breakdown or poor weather.

A Historic Flow Profile (HFP) is automatically generated which is a profile of typical traffic flow for a site for a given day or group of days. It is built up from the average traffic flow over a number of weeks (typically six) and held in the IMS system as a comparative reference for traffic flow at that site. Upper and lower thresholds are also calculated for each profile for use in raising alarms when traffic flow is significantly outside the profile for a given day.

3.3.3.5. INCIDENT RESPONSE MANAGEMENT

The Incident Management Systems is so named as all inputs, either detected automatically or entered manually, are automatically converted into incidents and a life-cycle for each incident is tracked and managed. The IMS arbitrates all the active incidents and their competing priorities and makes recommendations to the Operator as to what settings should be set on each of the appropriate signals and Variable Message Signs. In many cases the reprioritisation and sign setting is done automatically. The following figure, Figure 3.3.14, illustrates the differing incident response mechanisms within the IMS.

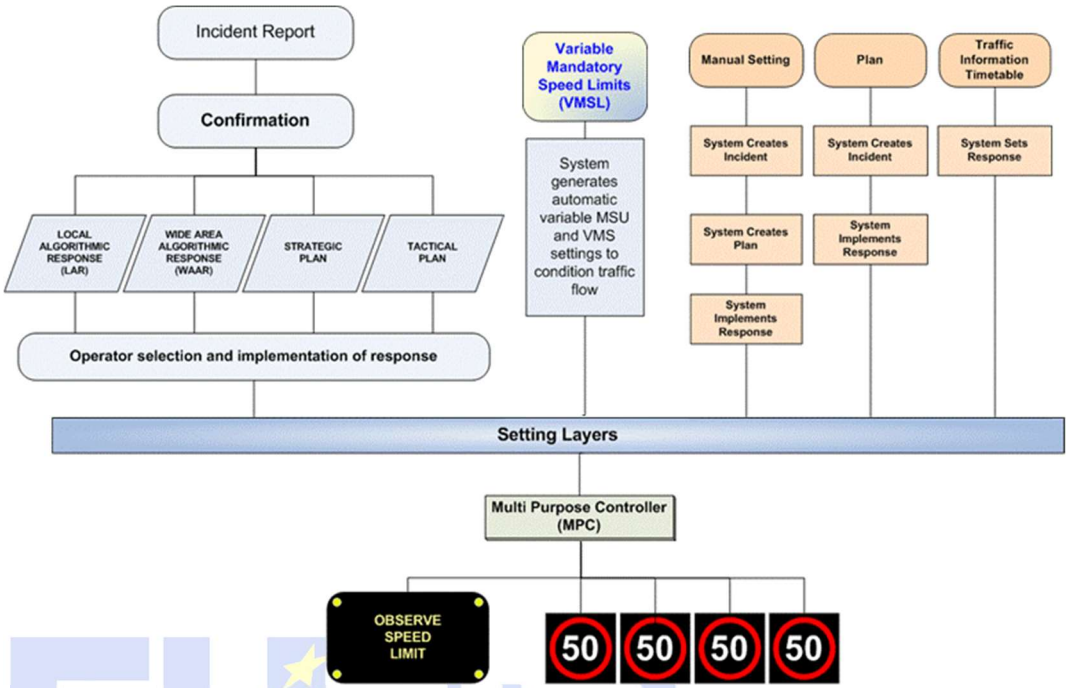

Figure 3.3.14. Incident Management System Response Mechanisms (source: Transport Scotland)

There is a focus within Scotland to maximise the use of the algorithmic response mechanisms, predominantly the LAR and WAAR, and minimise the overhead of managing problems and plans. However it is recognised that plans will always be a useful tool within the management of the network. The following table, Table 3.3.1, illustrates the different rules based response mechanism utilised in the IMS.

Table 3.3.1. Rules based responses

1	Local Algorithmic Response (LAR)	This provides an immediate response to safely manage an Incident, closing lanes, setting speed restrictions and warning drivers immediately upstream.
2	Wide Area Algorithmic Response (WAAR)	This provides a wide area strategic response to an Incident to warn drivers of potential hazards on the route ahead.
3	Strategic Plans	This is a pre-determined response to a known issue that has a specific response. This option is intended to inform rather than divert.
4	Tactical Plans	The tactical option is intended to allow the provision of a planned diversion response to an Incident where one has been planned.
5	Variable Mandatory Speed Limits	This is an Automatic variable response (when enabled) to congestion as it builds up on the network. The prime object is to reduce stop/start traffic behaviour and slow the onset of flow breakdown and queues.
6	Manual Settings	Manual settings allow any device to be set as required. The facility allows the operator to rapidly adjust the responses provided by the system by applying further MSU and VMS settings.
7	Manual Plans	Manual Plans support the setting of response plans for special events, and allows blanket responses to poor weather conditions to be implemented as required.

8	Traffic Information Timetable	The traffic information timetable provides a configurable means to schedule campaigns of background public information messages to be published on VMSs.

The subsequent figure, Figure 3.3.15, provides a representation of the flow of response handling within the IMS used in Scotland.

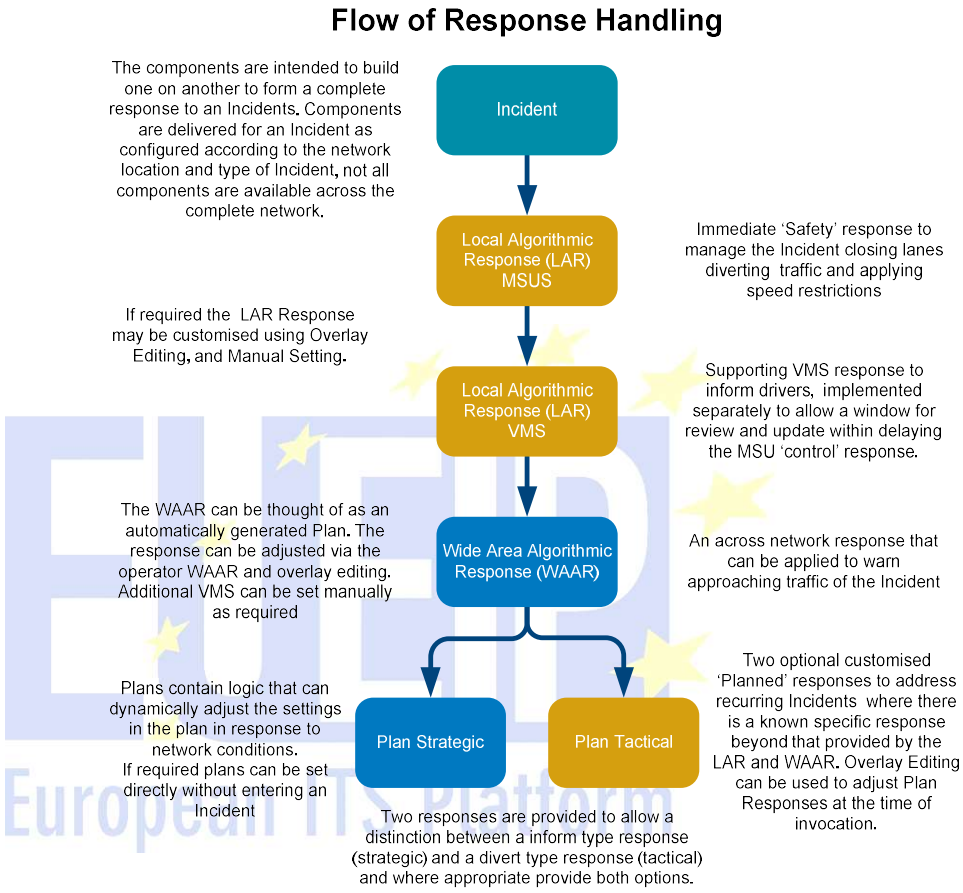

Figure 3.3.15. Flow of Incident Response handling in IMS (source: Transport Scotland)

3.3.3.6. WIDE AREA ALGORITHMIC RESPONSE

The WAAR can be viewed as an automatically generated Plan, based on configuration that meets most of the requirements for Plan based strategic responses. The purpose of the WAAR response is to provide essential strategic information, network-wide, as opposed to providing local, tactical re-routing. The selection of devices for the WAAR is made by the IMS 'walking the road' away from the Incident, adding devices into the selected set as they are encountered. The WAAR provides the operator with a Strategic Wide Area Response to an Incident, alerting traffic across the network.

The input for the algorithm is provided by the details of the Incident on the road network, for example the type and location of the Incident. The WAAR combines the details of the Incident with:

- Rules that indicate the construction of the legend to be used in the response
- A model that links the location of the Incident to the locations of the VMSs that can be used in the response

Different legend constructions are configured for each type of Incident and each type (size) of VMS. The legends included in the response are generated using variable components which are then completed based on the Incident Details. The components used include:

- Incident type - Accident, Roadworks etc.
- Route - the route that the Incident is on M8, M80, A770 etc.
- Direction - the direction affected - North, South East West
- Location - the description of the exact location of the Incident

Long and short forms of the components are used, and multiple constructions can be configured so that, where the constructed response does not fit a particular VMS, a shortened response is used

3.3.3.7. VARIABLE MANDATORY SPEED LIMITS

Variable Mandatory Speed Limits (VMSL) is an automatic background function to set variable mandatory speed limits in response to congested road network conditions. It provides congestion management by dynamically varying speed limits to suit road conditions. The intent of mandatory speed limits is to harmonise traffic speeds and reduce the severity of shockwaves (thereby reducing stop-start driving). Smoothing traffic flow in this way helps to delay the onset of flow breakdown and advances the recovery of traffic flow from congested conditions, making for more predictable journey times.

VMSL consists of two components:

- At the MPC outstation Flow/Speed data from monitoring sites is processed to identify the state of the site in terms of configurable Flow/Speed bands. Up to 7 Flow and 7 Speed bands can be defined.
- The IMS Instation processes this information and, on a configurable basis, associates the combined current flow and speed bands for a site with up to 4 congestion levels (5 including free-flow) as shown in Figure 3.3.16 and Figure 3.3.17. These reflect how well traffic is flowing at the site. Using this information, the VMSL functionality in the IMS sets configurable automatic speed restrictions and supporting VMS messages to condition traffic flow, reducing stop/start traffic behaviour and slowing flow breakdown and inhibiting the development of queues.

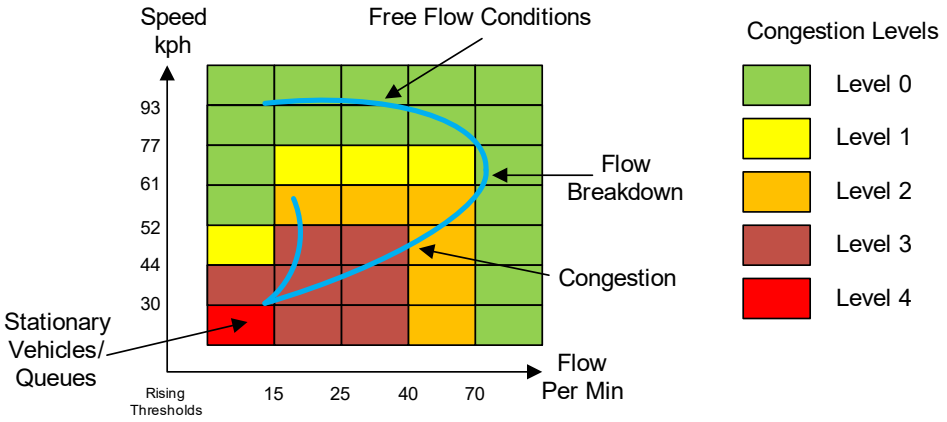

Figure 3.3.16. VMSL Congestion levels and Speed/Flow curve (source: Transport Scotland)

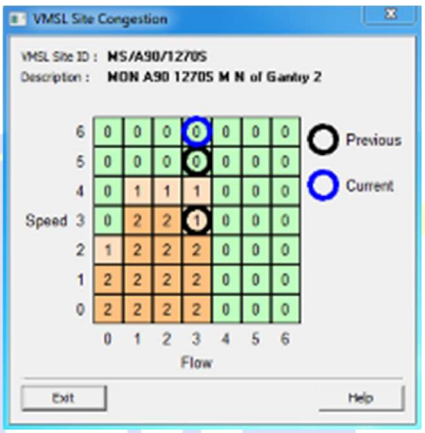

Figure 3.3.17. VMSL Site Congestion window (source: Transport Scotland, IMS)

Real-time traffic parameters are detected by roadside traffic monitoring units at 60 second intervals. From these traffic flow and occupancy levels are monitored and analysed at the roadside MPCs.

The Variable Speed Limit function controls the speed of traffic during the onset of congestion and prior to traffic flow breakup and queuing. Traffic conditions are categorised by the Incident Management System (IMS) between 0 (no congestion) and 4 (heavy congestion) representing speed limits from 60 mph to 30 mph respectively in 10 mph steps. The appropriate speed limit for the current traffic conditions is determined from a congestion index. This index is a function of the traffic speed and flow values, although to defer the onset of flow breakdown the McMaster algorithm queue response will be activated to set the speed limit to a primary setting of 40 mph.

4. Conclusions

4.1. Stakeholder workshop

On 21st and 22nd of September a workshop was organised in Madrid to present to relevant stakeholders the preliminary results of activity 4.2 on automation of road operator ITS and automated vehicles.

The final session of the first day of the workshop was an open discussion centred around performing an on the spot SWOT analysis for the implementation of autonomic and automated functions in traffic management centres. The following main ideas were raised:

- The speed and level of implementation will always be dependent on the policy framework and financing

- The use of automated vehicles will not make traffic management obsolete or unnecessary, especially in the mixed traffic situations, which is expected to be the case for quite a long time

- Investments in infrastructure are very important but it is not always easy to predict what requirements the future will bring

- When compared to automated vehicles, the automation of traffic centres is not just another feature, but actually a technological evolution of the systems

The workshop facilitated very interesting and fruitful discussions in both days. It fully reached the objectives of SA4.2 and it helped gather useful feedback from the stakeholders.

From the presentations in the first day we could see that, for example, in Germany ITS and automation is needed and it brings concrete benefits. The same conclusion comes from Finland where operators are overloaded and need automation to support their tasks. Some road operators already use automation, there are plans for further developments and some functions that are now manual could be automated in the future. In general technology is available, still there are some challenges: communication solutions, big data, correct response in adverse situations (like false detections).

4.2. General conclusions

This document introduced the concept of autonomic systems in TMCs and underlying functions that define their behaviour. The benefits they can bring to traffic management centres, implementation costs and operational aspects were also briefly discussed.

The major objective of this deliverable was to study if there are autonomic aspects in existing traffic management centres, both with regard to their operations and data processing. Information was gathered and presented for traffic management centres from Germany, Finland, Spain, Scotland and the Netherlands.

The conclusion of these studies is that none of this centres was originally planned to have fully autonomic functions. However, they have several automated operations and data processing which can be considered very similar to the self-management and partially similar to the self-optimizing autonomic functions. This automation is a good foundation to further develop the TMCs towards fully autonomic systems.

The ultimate goal of Task 4 within SA4.2 is to prove that a TMC build on autonomic principles brings more benefits that a traditional one and to set guidelines for such an implementation. Therefor future activities of Task 4 will propose solutions to introduce automation and autonomic functions taking into account all the developments and challenges.

In general, it can be concluded that automation is highly beneficial for TMCs and autonomic functions can bring further enhancements beyond automation.

Annex 1 – Detailed description of sensors

Traffic sensors

INTRUSIVE TRAFFIC SENSORS

A sensor will be intrusive when its location is directly on the road, i.e. in contact with the ground.

In terms of installation and maintenance, they are complex and costly due to the disruption on the road traffic. Moreover, they are more likely to cause damage to vehicles.

INDUCTIVE LOOPS

Inductive loops consist of isolated electrical cables which can take different configurations: square, rectangular, diamond shaped, circular or octagonal. Its operation is based on impedance variation recorded in the loop to the passage of a vehicle. The loop consists of four parts:

- A tie or a wire loop formed by a cable giving one or more turns, superficially buried in the pavement of the road.
- A wire of introduction linking the tie with a junction box.
- Another cable to link the junction box and controller.
- An electronic unit located in the control booth. This unit contains an oscillator and amplifiers which excite the inductive loop.

If a vehicle (or any electrically conductive object) comes into this magnetic field or rather, any component of the magnetic field is normal to the area of the object, a current is induced in the wire. This generates another magnetic field opposite to the first magnetic field. This fact leads to a decrease in the overall magnetic field. Considering that the loop inductance is proportional to the magnetic flux, the inductance decreases.

Inductive loops provide much information about the condition prevalent of traffic, including flow, occupancy, type of vehicles and speed. It will be necessary to provide double loops to measure the speed of a car.

Signature data depends on size, metal mass, number of axles, distance between the metal surfaces on the undercarriage of the vehicle and the road surface, as shown in Fig 1.

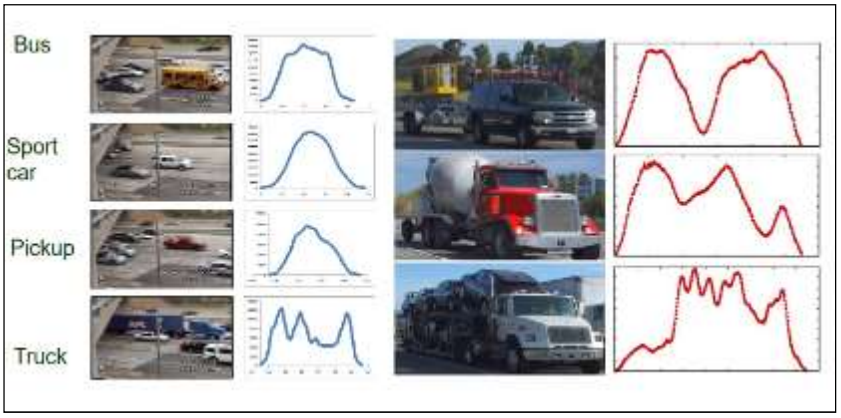

Fig 1. Inductive loops signature for different vehicles (source: CLR Analytics. Innovate Transportation Solutions)

Accuracy of the system depends largely on the process installation and calibration. Loop detectors are always limited by their inability to detect stationary vehicles.

Inductive loops may be used alone, or can be incorporated with other traffic systems to provide information regarding vehicle presence.

A good detection system is maintained within an accuracy of 5%. The effectiveness of management strategies such as incident detection depends on the reliability and accuracy of loop detectors. Some configurations of loop detectors provide different electromagnetic fields which can affect the detection of vehicles in adjacent lanes.

Many traffic management centres use a combination of manual inspection and reliability tests to detect big mistakes produced in field.

There are advanced techniques to detect small mistakes that consist in comparing data from an inductive loop with data from inductive loops of the same station. A second strategy compares the data loop (volume, occupancy and speed) against the actual thresholds periodically at intervals of time. Other more complex algorithms use a multi-system comparison of the flow ratio - occupation with maximum speed and minimum expected.

Sensors are unreliable due to their large number of faults (faults of 0.13 to 0.29 per turn and year), affecting up to 50% of these sensors in a single year.

The margin of error can be quantified on average to the following percentages: 5% in volume, 10% in speed and classification.[6]

There are three types of alarms operation for double inductive loops: congestion alarm when averaged traffic flow speed and density of traffic go below a given threshold, a vehicle's driving in reverse direction and a vehicle's driving abnormally slow compared to the overall traffic flow. In case of simple inductive loops, only one type of alarm will be generated, congestion alarm.

[6] Fusión de datos para la obtención de tiempos de viaje en carretera. David Abeijón, Francesc Soriguera and Leif Thorson. June 2007.

MAGNETIC FIELD TRAFFIC SENSORS

Magnetic sensors are passive devices that detect the presence of a ferrous metal object through the perturbation (known as a magnetic anomaly) metal causes in the Earth's magnetic field. Two examples are shown in Fig 2.

One advantage over inductive loops is that the magnetic field sensors can be used in parking, since the latest versions can detect the presence of vehicles.

Magnetic detector

Magnetic detectors are designed to detect the presence or passage of a vehicle by measuring the perturbation in the Earth's quiescent magnetic field caused by a ferrous metal object (e.g. its bodywork) when it enters the detection zone of the sensor.

The device is able to detect weak fields of specific frequencies, allowing coding to differentiate the passage of authorized or unauthorized vehicles.

There are two types of magnetic detectors: AMR (Anisotropic Magnetoresistance) and GMR (Giant Magnetoresistance).

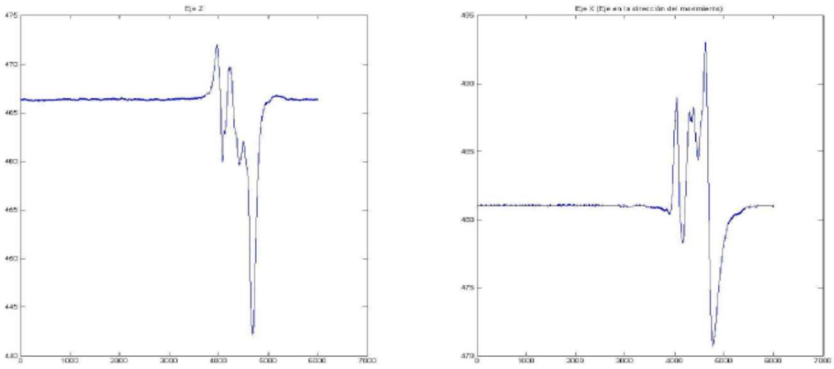

Fig 2. Graph of the variation of the magnetic signal when a vehicle passes (source: Departamento de Física Fundamental, Experimental, Electrónica y Sistemas. Facultad de Física, Universidad de La Laguna, España)

Early magnetic sensors were utilized to determine if a vehicle had arrived at a "point" or small-area location. They actuated controller phases that operated in the locking detection memory mode.

In general, magnetic detectors do not detect stopped vehicles, since they require a vehicle to be moving. However, multiple units of some devices can be installed and used with specialized signal processing to generate vehicle presence.

Detectors are not able to detect stopped vehicles, but can provide volume, occupancy data based on the detection zone size and an assumed vehicle length.

In those detectors which cannot detect stopped vehicles, minimum speeds of 3 to 10 mi/h (5 to 16 km/h) are required to produce an actuation. The signal processing is designed to ignore the lower magnitude signals generated in adjacent lanes and analyse only the larger signals produced by vehicles in the lane containing the sensor. A schematic of the installation procedure is shown in Fig 3.

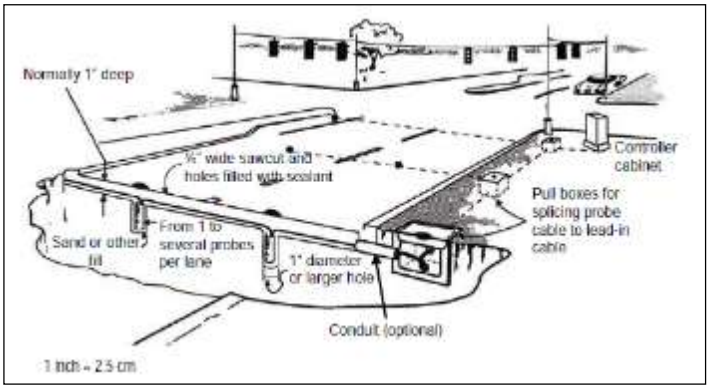

Fig 3. Magnetic sensor installation (source: Traffic Detector Handbook. Volume I and II. Third Edition. U.S. Department of Transportation. October 2006)

Its reliability is higher than 98% in the detection of traffic volume and speed of circulation, and 95% in the determination of the occupation of the road and vehicle size within the range of temperature from -20˚C to +65˚C.[7]

Measures in AMR range from μG to 50 G. GMR system can measure magnetic fields from 1 mG to 1000 G, but its measure band is smaller than AMR one.[8]

Magnetic sensors also warn TMCs and drivers, activating a congestion alarm, when traffic conditions go below a given threshold.

Two axis fluxgate magnetometer

The other type of magnetic field sensors detects changes in the vertical and horizontal components of the Earth's magnetic field produced by a ferrous metal vehicle.

Two-axis fluxgate magnetometers contain sensors that detect both the vertical and horizontal components of the Earth's magnetic field and any disturbances to them. One of the secondary windings in a two-axis fluxgate magnetometer senses the vertical component of the vehicle signature, while the other, offset by 90 degrees, senses the horizontal component of the signature. The horizontal axis of the magnetometer is usually aligned with the traffic flow direction to provide in-lane presence detection and adjacent lane vehicle rejection.

Fluxgate magnetometers measure the passage of a vehicle when operated in the pulse output mode. In the presence mode, they give a continuous output as long as either the horizontal or vertical signature exceeds a detection threshold.

The data provided by old two axis fluxgate magnetometers were the same as from the inductive loops. They had the advantage that they cannot be disrupted by steel support structure or weaken the existing structure. Two closely spaced sensors were preferred for determining occupancy and speed.

The infusion of modern digital processing and Radio Frequency (RF) communications technology in the area of magnetic anomaly detection have generated new designs, such as the Self-Powered Vehicle Detector (SPVD) and Groundhog magnetometers, justifying a

[7] U-Flow Traffic Sensor provided by "Urbiotica"

[8] Sistemas de monitorización de vehículos basado en sensor magnético. Rubén Calle Berges. September 2015

reassessment of their supplementary role in vehicle detection. In addition, an array of magnetometers sharing a common signal processor has the potential to locate, track, and classify vehicles in a multilane scenario using a row of above-ground sensors

Fig 4 shows the SPVD. Applications include permanent and temporary installations on freeways and surface streets or where mounting under bridges or viaducts is desired.

Fig 4. SPVD magnetometer system (source: DGT)

Fig 5 illustrates some of the Groundhog magnetometer sensors. The G-1 model provides volume, lane occupancy and road surface temperature. The G-2 adds vehicle speed reported in up to 15 bins, vehicle class in terms of vehicle length reported in up to 6 bins, and a wet/dry pavement indicator. In addition to the previously mentioned traffic parameters, the G-2wx provides chemical analysis for measuring the quantity of anti-icing chemicals on the road surface. The G-4C provides vehicle count only, while the G-4CS provides vehicle count, speed, and classification. The G-4WX adds environmental monitoring of road surface temperature from -67 °Fahrenheit (F) to 185 °F (-55 ° Celsius (°C) to 85 °C) and road surface wet or dry condition to the G-4CS data set.[9]

Fig 5. Groundhog magnetometer sensors (source: DGT)

[9] Traffic Detector Handbook. Volume I and II. Third Edition. U.S. Department of Transportation. October 2006

A magnetometer can detect two vehicles separated by a distance of 1 foot (0.3 m). This potentially makes the magnetometer as accurate as or better than the inductive-loop detector at counting vehicles.

Magnetometers are sensitive enough to detect bicycles passing across a 4 ft (1.2 m) span when the electronic unit is connected to two sensor probes buried 6 inches (16 cm) deep and spaced 3 ft (0.9 m) apart. Magnetometers can hold the presence of a vehicle for a considerable length of time and do not exhibit crosstalk interference.[10]

Alarms for two axis fluxgate magnetometers are identical to alarm system in magnetic detectors.

To maximize the accuracy and detail of information to be extracted, some magnetometers utilize self-learning artificial neural networks in the data processing. These networks are trained with large amounts of data to recognize almost every possible vehicle type and situation that might occur on the roads.[11]

PNEUMATIC ROAD TUBES

This system consists of a detector rubber shaped closed tube placed transversely to the carriageway. At the other end, the tube terminates in a flexible metal membrane. When passing over the wheels of the vehicles increases the air pressure inside, moving the metal membrane which closes an electrical contact.

The counting device is operated by this electrical pulse, and counts the passage of a vehicle to receive two pulses corresponding to the passage of the front and rear wheels of the vehicle.

This type of detector is very useful in temporary or short-term installations, since the rubber tubes are easily placed on the roadway and the counter is powered by a battery.

Placing two tubes at a short distance as shown in Fig 6, it is possible to calculate the vehicle speed (double pneumatic road tube).

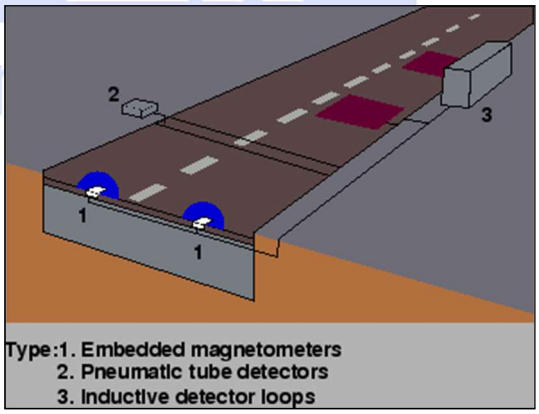

Fig 6. Example of combination of intrusive sensor technologies (source: Department of civil engineering, Indian Institute of Technology Bombay)

[10] Traffic Detector Handbook. Volume I and II. Third Edition. U.S. Department of Transportation. October 2006

[11] Magnetometer sensors. Classification with neural networks. Sensebit

This technology can obtain different variables such as traffic volume, speed (using the double tube to which reference is made) and classification (based on the number and spacing between axes) of the vehicle.

PIEZOELECTRIC SENSORS

Detection is based on the pressure generated by the vehicle passing over piezoelectric sensors. Detecting the passage of the vehicle is based on the electric charge generated in the piezoelectric material when depressed by a wheel. The electrical signal is transmitted to a counter or to a computer with software suitable for processing, as same as road tubes.

There are two types of formats: Class I and Class II. Class I sensors are very accurate for use in moving weight applications, while Class II sensors are used in measures of speed and vehicle classification. Coaxial cable connections to the sensor are completely sealed within the polyurethane cover.

Another type of piezoelectric sensor, highway weigh-in-motion (WiM) systems are capable of estimating the gross vehicle weight of a vehicle and the portion of this weight carried by each wheel assembly (half-axle with one or more tires), axle, and axle group on the vehicle (ASTM E1318-02, 2002). WiM data are used by highway planners, designers, and enforcement agencies.

A single sensor is sufficient for counting axles, allowing obtaining the data traffic flow in a very simple way. It is also used as a detector input or output of vehicles in parking for driving the barrier or to control safety devices. It is sensitive to all kinds of vehicles, and sensor Class I, more accurate, can be used to determine the weight per axle (an example is shown in Fig 7).

In conjunction with an inductive loop (which detects presence), one piezoelectric sensor allows a wide information such as the number of axles per vehicle, or when a Class I sensor is used, it allows to determine the weight per axle and total vehicle weight.

Fig 7. Capacitance mat sensor (source: DGT)

Two sensors placed perpendicular to the direction of traffic and known distance are a very accurate method of measuring speed.

Using an inductive loop detector type with a pair of piezoelectric sensors can obtain the classification of the vehicle as well as its speed and weight (if the piezoelectric sensors used are Class I). In this case, it can be determined violations excess axle weight and total weight.

Placing a piezoelectric sensor perpendicular to the traffic flow and two piezoelectric sensors at a known angle before the first one, it is possible to determine the lateral position of each vehicle relative to the road, the vehicle's width and weight distribution per axle and wheel.

WiM systems provide highway planners and designers with time and date of traffic volume, speed, vehicle classification based on number and spacing of axles, and the equivalent single axle loading (ESAL) that heavy vehicles place on pavements and bridges.

Data accuracy of this type of systems depends on the configuration installed. To optimise its performance and accuracy, the system installed may be equipped with a neural network algorithm to compensate sensors response to temperature variations.

Despite the compensation produced by algorithm, the system seems to be extremely sensitive to temperature. The average error tends to decrease in summer, when the temperature of the road surface is high, and to increase in winter, when the temperature lowers.

The sensors have to work with range of temperatures from -15°C to +80°C, since as it mentioned above, sensor sensitivity varies with temperature, (temperature coefficient of 0.3% per °C).[12]

Regarding WiM systems, California Department of Transportation (Caltrans) provides the following performance requirements:

Tab 1. WiM systems performances

Parameter	Mean	Standard Deviation
Single axle vehicle weight	± 5%	8%
Tandem axle vehicle weight	± 5%	6%
Gross weight	± 5%	5%
Axle spacing	± 150 mm	300 mm
Vehicle length	± 300 mm	460 mm
Vehicle speed	± 1.6 km/h	3.2 km/h

FIBRE OPTIC SENSORS

Fibre optic traffic sensors are best suited for axle detection. They work for any speed, in any pavement with the highest accuracy and outstanding durability.

This system is based on the change in the optical signal parameters due to optic fibre strain under the weight of a passing transport vehicle. When a vehicle passes over the detector, a decrease in optical transmittance is produced. This variation is interpreted by an optoelectronic interface that determines the presence of a vehicle and even the type of vehicle in question.

They need LED power to operate properly whereas they do not pick up any energy from the road which makes them insensitive to any road vibrations. They are not metallic, so they are immune to radio frequency and magnetic fields.

[12] Tyssa. Ingeniería del tráfico, S.A. de C.V. Sensor piezoeléctrico para montaje superficial

Fig 8. Example of fibre optic sensor (source: DGT)

Its use is analogous to piezoelectric sensors, but covering speeds from 0 km/h to 250 Km/h, so are the only sensors that allow sort according to the number of axes in situations of circulation to turn wheel, start-stop, etc.

They are useful for monitoring the traffic entering and leaving guarded areas, counting traffic on public roads as well as in determining lane occupancy at traffic lights. When installing sensor arrays, the sensors may also be used to provide additional information: measure the speed, wheel base of a vehicle and also to determine the number of axles and vehicle type

There are various factors which affect the accuracy of fibre optic sensors measurement:

- Features of the installation in the roadway.
- Nonlinearity and inertia of the sensor.
- Thermal effect, the inertial force of the vibrating vehicle.
- Extremely short time of the load standing on the sensor.

NON-INTRUSIVE TRAFFIC SENSORS

Unlike intrusive sensors, these detectors do not directly affect traffic during operation, as they are placed in overhead or lateral position on the road without coming into contact with the road. Generally used for location or existing infrastructure (bridges over the track, signalling panels porches or tolls), own porches or posts.

MICROWAVE RADAR SENSORS

Two types of microwave radar sensors are used in roadside applications: those that transmit continuous wave (CW) Doppler waveforms and those that transmit frequency modulated continuous waves (FMCW). The traffic data they receive are dependent on the respective shape of the transmitted waveform.

Microwave radar sensors may be mounted over the middle of a lane to measure approaching or departing traffic flow parameters in a single lane or at the side of a roadway to measure traffic parameters across several lanes.

Forward-looking, wide beamwidth radars gather data representative of traffic flow in one direction over multiple lanes. Forward-looking, narrow beamwidth radars monitor a single lane of traffic flowing in one direction. Side-mounted, multiple detection zone radars project their detection area (e.g. footprint) perpendicular to the traffic flow direction. These sensors provide data corresponding to several lanes of traffic, but generally not as accurately as the same radar mounted in the forward-looking direction can do. Side-mounted, single-

detection zone radars are typically used to detect vehicle presence in one or more lanes at signalized intersections.

CW Doppler Radar

This sensor is also referred to in some literature as a microwave or microwave Doppler sensor.

The constant frequency signal (with respect to time) allows vehicle speed to be measured using the Doppler principle. Accordingly, the frequency of the received signal is decreased by a vehicle moving away from the radar and increased by a vehicle moving towards the radar. Vehicle passage or count is denoted by the presence of the frequency shift.

The chief use of the simple unmodulated CW radar is for the measurement of the relative velocity of a moving target. The principal advantage of CW Doppler radar over other non-radar methods of measurement of speed is that they do not need any physical contact between the measuring device and the object whose speed is being measured.

Vehicle presence cannot be measured with the constant frequency waveform since only moving vehicles are detected.

Fig 9. TC-20 Doppler microwave radar (source: DGT)

Sensors are high average accuracy for speed variables (error: 1-8%) and volume (error: 2-14%) and low for classification. Moreover, they are very sensitive to environmental conditions, being insensitive to inclement weather.

One of the factor that most affected is electromagnetic interference in case of presence of high-powered radars.[13]

FMCW Radar

The second type of microwave sensor used in traffic management and control applications is FMCW radar. The frequency of this signal changes over time, generally in a sweep across a set bandwidth. The difference in frequency between the transmitted and received (reflected) signal is determined by mixing the two signals, producing a new signal which can be measured to determine distance or velocity. A saw-tooth function is the simplest, and most often used, change in frequency pattern for the emitted signal.

[13] Fusión de datos para la obtención de tiempos de viaje en carretera. David Abeijón, Francesc Soriguera and Leif Thorson. June 2007.

FMCW radar differs from classical pulsed radar systems in that an RF signal is continuously output. Consequently, time of flight to a reflecting object cannot be measured directly. Instead, the FMCW radar emits an RF signal that is usually swept linearly in frequency. The received signal is then mixed with the emitted signal and, due to the delay caused by the time of flight for the reflected signal, there will be a frequency difference that can be detected as a signal in the low frequency range.

When mounted in a side-looking configuration, multilane FMCW radar sensors can monitor traffic flow in as many as eight lanes. With the sensor aligned perpendicular to the traffic flow direction, the range bins are automatically or semi-automatically (depending on the sensor model) adjusted to overlay a lane on the roadway to enable the gathering of multilane traffic flow data. FMCW radars can also use Doppler to calculate the speed of moving vehicles.

Presence-detecting radars, such as the models illustrated in Fig 10, control left turn signals, provide real-time data for traffic adaptive signal systems, monitor traffic queues, classify vehicles in terms of vehicle length, and collect occupancy and speed (multi detection zone models only) data in support of freeway incident detection algorithms.

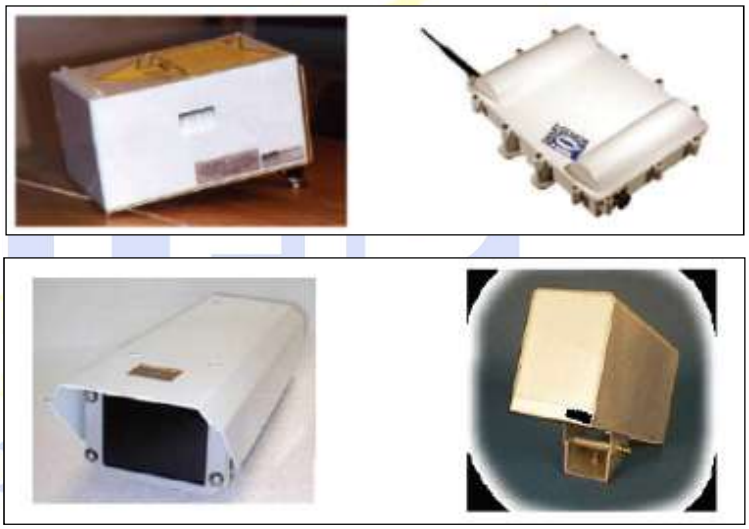

Fig 10. FMCW microwave radars (source: Traffic Detector Handbook, Volume I and II, Third Edition. U.S. Department of Transportation, October 2006)

CW Doppler radars are used to measure vehicular speed on city arterials and freeways, but cannot detect stopped vehicles. Multi detection zone microwave presence-detecting radars are gaining acceptance in electronic toll collection and automated truck weighing applications that require vehicle identification based on vehicle length.

FMCW radars can have very high resolution for ranging, velocity and imaging application. A distance measurement resolution of 2 cm can be easily achieved over 20-30 meters.

Accuracy for non-moving targets is better than for moving targets, and requires less processing power. Measurements of moving targets are of course possible, but require more powerful algorithms and hardware.

Due to the short wavelength of the electromagnetic radiation used, mm-wave systems have excellent performance in rain, humidity, fog and dusty conditions. The short wave-length

means that raindrops, water vapour or dust particles do not block wave propagation easily. FMCW radars are also immune to effects from temperature differences, or high temperatures.[14]

INFRARED SENSORS

Active and passive infrared sensors are manufactured for traffic management applications. Active infrared sensors illuminate detection zones with low-power infrared energy transmitted by laser diodes operating in the near infrared region of the electromagnetic spectrum at 0.85 µm. A portion of the transmitted energy is reflected or scattered by vehicles back toward the sensor.

Passive sensors transmit no energy of their own. Rather, they detect energy from two sources: energy emitted from vehicles, road surfaces and other objects in their field of view and energy emitted by the atmosphere and sun that is reflected by vehicles, road surfaces, and other objects into the sensor aperture.

The energy captured by active and passive infrared sensors is focused by an optical system onto an infrared-sensitive material mounted at the focal plane of the optics. With infrared sensors, the word detector takes on another meaning – namely, the infrared-sensitive element that converts the reflected and emitted energy into electrical signals.

Real-time signal processing is used to analyse the received signals for the presence of a vehicle. The sensors are mounted overhead to view approaching or departing traffic. They can also be mounted in a side-looking configuration. Infrared sensors are utilized for signal control; volume, speed, and class measurement; detection of pedestrian in crosswalks; and transmission of traffic information to motorists.

Active infrared sensor

The active infrared laser sensor has two sets of optics. The transmitting optics split the pulsed laser diode output into two beams separated by several degrees.

The receiving optics has a wider field of view, so they can better receive the energy scattered from the vehicles. The multiple beams allow laser radar to measure vehicle speed by recording the times at which the vehicle enters the detection area of each beam. Since the beams are a known distance apart, the speed can be calculated.

Active infrared sensors provide vehicle presence at traffic signals, volume, lane occupancy, speed, length assessment, queue assessment, and classification. Modern laser sensors produce two -and three- dimensional imaginary of vehicles suitable for vehicle classification, as illustrated in Fig 11.

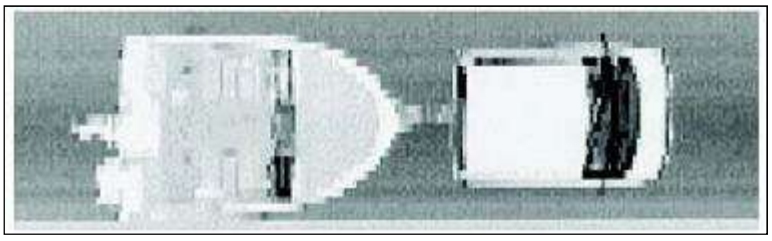

Fig 11. 3-D laser radar range image of a van pulling a boat (source: DGT)

[14] FMCW radar sensors. Application Notes. Siversima. June 2011.

Active infrared sensors also communicate traffic information to motorists by modulating and coding the infrared beam with the appropriate data as illustrated in Fig 12.

Operation may be affected by fog when visibility is less than ≈20 feet (6 meters) or blowing snow is present.

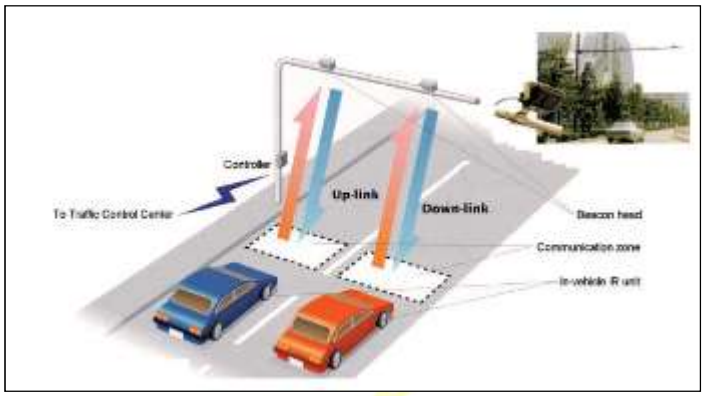

Fig 12. Active infrared sensor installed for transmitting traffic conditions to motorists (source: DGT)

Passive infrared sensor

Nonimaging passive infrared sensors used in traffic management applications contain one or several (typically no more than five) energy-sensitive detector elements on the focal plane that gather energy from the entire scene. The detector in a nonimaging sensor generally has a large instantaneous field of view. Instantaneous field of view is equal to the angle (i.e. in the x-y plane) subtended by a pixel. Objects within the scene cannot be further divided into sub-objects or pixels with this device.

Infrared sensors are used for signal control; volume, speed, and class measurement; detection of pedestrians in crosswalks; and transmission of traffic information to motorists. Passive infrared sensors with a single detection zone measure volume and lane occupancy by responding to vehicle passage and presence.

Those with multiple detection zones can also measure vehicle speed and length (to the extent that vehicles are detected in one or more detection zones a known distance apart).

When a vehicle enters a passive sensor's field of view, detected energy changes due to the presence of the vehicle. The difference in detected energy created by the vehicle is described by radioactive transfer theory.

Fields of view can be tailored through the optical design to accommodate different requirements, such as stop line presence detection and presence detection in the approach to an intersection. A long focal length lens eliminates adjacent lane detection when sensing vehicles over 100 feet (30.5 m) from the sensor.

Multi-channel and multi-zone passive infrared sensors measure speed and vehicle length as well as the more conventional volume and lane occupancy. These models are designed with dynamic and static thermal energy detection zones, which the functionality of two inductive loops. The time delays between the signals from the three dynamic zones are utilized to measure speed. The vehicle presence time from the fourth zone is used to calculate the lane occupancy of stationary and moving vehicles.

The passive sensor has average accuracy in determining the volume (error: 1-10%) and low accuracy in speed (error: 10.8%) and classification.

Their sensitivity to environmental conditions is low for passive sensor, being the factor that most affects it snow, rain and fog.

ULTRASONIC SENSORS

Ultrasonic sensors transmit pressure waves of sound energy at a frequency between 25 and 50 kHz, which are above the human audible range.

Pulse-shape waveforms measure distances to the road surface and vehicle surface by detecting the portion of the transmitted energy that is reflected towards the sensor from an area defined by the transmitter's beamwidth. When a distance other than that to the background road surface is measured, the sensor interprets that measurement as the presence of a vehicle. The received ultrasonic energy is converted into electrical energy. This energy is then analysed by signal processing electronics that is either collocated with the transducer or placed in a roadside controller.

Most ultrasonic sensors operate with pulse waveforms and provide vehicle count, presence, and occupancy information.

Pulsed energy transmitted at two known and closely spaced incident angles allows vehicular speed to be calculated by recording the time at which the vehicle crosses each beam. Since the beams are a known distance apart, the speed can be calculated as beam separation distance divided by the time to traverse the beams. The preferred mounting configurations for range measuring, pulsed ultrasonic sensors are on posts, looking from an overhead position, and side viewing, as shown in Fig 13.

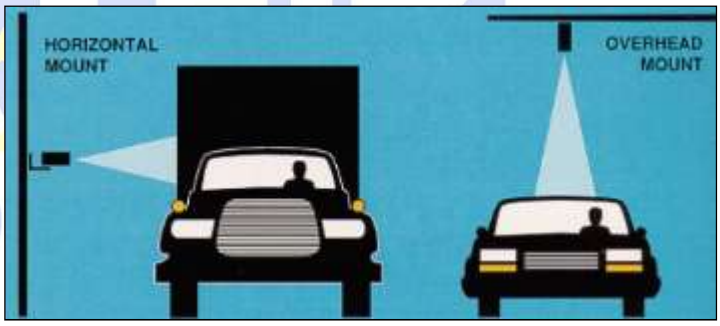

Fig 13. Mounting of ultrasonic range-measuring sensors (source: DGT)

The ultrasonic sensor is very accurate in determining the volume (error: 1.2-2%) and imprecise in defining speed and classification.[15]

Temperature change and extreme air turbulence may affect the performance of ultrasonic sensors. Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles travelling at moderate to high speeds as an insufficient number of pulses is transmitted and reflected from the vehicle while in the sensor's detection zone.[16]

[15] Fusión de datos para la obtención de tiempos de viaje en carretera. David Abeijón, Francesc Soriguera and Leif Thorson. June 2007.

[16] Traffic Detector Handbook. Volume I and II. Third Edition. U.S. Department of Transportation. October 2006

LICENSE PLATE RECOGNITION

An Automatic License Plate Reader (ALPR) is an image-processing technology used to identify vehicles by their license plates. It is a special form of OCR (Optical Character Recognition) where algorithms are employed to transform the pixels of the digital image into the text of the number plate.

The system uses illumination (such as Infra-Red) and a camera to take the image of the front or rear of the vehicle, then image-processing software analyses the images and extracts the plate information. This data is used for enforcement, data collection, and (as in the access-control system showed in Fig 14) can be used to open a gate if the car is authorized or keep a time record on the entry or exit for automatic payment calculations.

The LPR system significant advantage is that it can keep an image record of the vehicle which is useful in order to fight crime and fraud. An additional camera can focus on the driver face and save the image for security reasons. Additionally, this technology does not need any installation per car.

The component parts of the License Plate Recognition are:

- Capture and Lighting Unit: consists of camera, optics, lighting and filters. It is responsible for capturing images of vehicles with sufficient to allow their identification and reading your plate quality. In the license plate frame will have at least 14 pixels high.
- Control Unit: analyses the captured images and is responsible for the recognition of license plates. It shall consist of at least real-time clock, OCR engine, electronic control and synchronization, and optionally communications line.
- Local Unit Process: is responsible for: managing all capture points situated in one location, data conversion, storage, information management and communication with the Centre and Control via Ethernet interface.

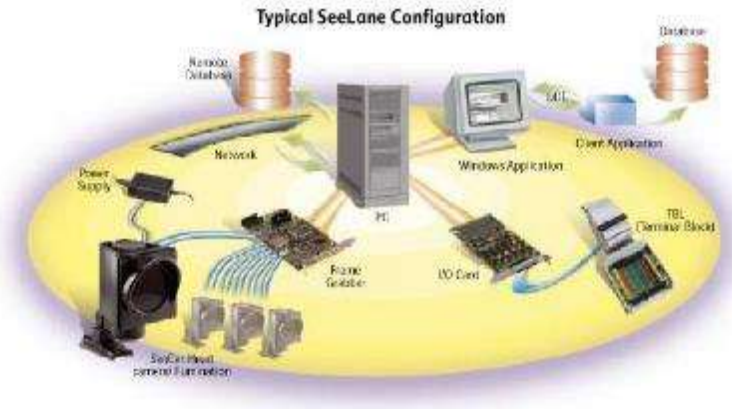

Fig 14. Typical see-lane configuration (source: DGT)

By identifying the same vehicle in the input section and the output, it can be calculated the average travel time of vehicles on that section, information that is very valuable from the point of view of traffic management, as it is an objective measure of the state of circulation.

The license plate readers have the following functional features:

Tab 2. LPR features

Moving license plate reading	Recognize plates moving vehicles whose speed measurement range is 1 to 300 Km/h.
High degree of reliability in character recognition	It reaches 98 percent.
High-speed capture	The license plate reading camera can process from 40 to 200 frames / second, depending on the business model.
Storage of historical data	It has a historic local registration of vehicles detected with photo documentation. The storage capacity is greater than 200,000 images.
Data security.	The data is encrypted and communications (data reading requires possession of the keys) and digitally signed (ensures the author).
Range work.	The operating temperature range is -20 to 55 ºC, at a humidity of 5% to 90%
Shelf life	Shelf life of these sensors is over 10 years.

AUTOMATIC INCIDENT DETECTION

Automatic Incident Detection AID is based on video analytics technologies, applied to automatic real time detection of traffic incidents on roadways. It uses images from CCTV video cameras.

Those images are processed either by a detection platform called Analyser or directly within the traffic sensor or the smart camera. The video analytic technologies automatically select pertinent information, such as incident and traffic data.

AID provides traffic operators with alarms seconds after an event has occurred, even before consequences of the incident can be noticed by the operator or any traditional loop-based detection system. The AID algorithm extracts information on objects from a number of video images within a monitored area.

At start up, a reference image (background) is built, and continuously updated.

- The presence of vehicles is detected within each image by a double comparison between the current image, the immediately previous one, and the reference image.
- Vehicles are identified by means of morphological filters that associate a marker with each object in motion (vehicle, pedestrian, etc.).
- The algorithm tracks the marker (vehicle) throughout the sequence of images (tracking), and analyses its movement to build up a time and space trajectory. Trajectory analysis allows filtering out potential events that do not correspond to a likely behaviour (presence of shadows…)
- Active occlusion management mechanisms allow preserving tracking markers in case of temporary occlusion of vehicles (useful in case of congestion). AID keeps track of any vehicle when visibility is granted again.

The tracking system generates data such as vehicle presence, stopped vehicles, or speed. AID spatial analysis is the basis for true traffic measurements.

AID can cover up to 3 lanes of traffic plus one emergency lane. It automatically detects incidents, on all types of lanes (traffic lane, emergency lane, access ramp, hard shoulders, slip roads) under every traffic configuration (fluid, congestion, stop & go, etc.).

Stop vehicle in fluid traffic

An alarm is triggered when a vehicle stops on the roadway.
A linear movement followed up by a stop produces a ”stopped vehicle” detection. It is a highly reliable detection both in terms of detection rate and low false alarms rate due to the tracking technology.

Stop vehicle in congested traffic

The video analytics discriminates the context of traffic to filter normal stops in congestion (due to stop and go) and abnormal stop.
A vehicle in trouble stays longer still than any vehicle stopped by traffic congestion. The algorithm analyses the duration of the stop to produce the alarm.

Traffic slowdown, traffic congested

An alarm is generated when averaged traffic flow speed and density of traffic go below a given threshold.
Adjustable thresholds allow adapting detection to particular traffic congestion (frequency of congested traffic).

Wrong way

An alarm is triggered when a vehicle is driving in reverse direction.
The algorithm tracks reverse direction movement over a distance that varies with site configuration.

Slow vehicle

An alarm is triggered when a vehicle drives abnormally slow.
Dynamic traffic adaptation allows this type of detection when a vehicle drives abnormally slow compared to the overall traffic flow.

Pedestrian

Detection of pedestrian is performed on hard shoulders and/or emergency lanes.
Moving pedestrians are detected when they are walking on the sidewalk.

Loss of visibility

Smoke detection in tunnels derives from a visibility check performed on detection zones covering the whole image. An alarm is raised when several detection zones fade away or disappear.
Loss of visibility can be caused by smoke, dust or fire compromising the safety of drivers.

Debris

An alarm is raised when a small still object is detected on the roadway.

Floating car data (FCD)

Floating Car Data (FCD) is emerging as a means of monitoring traffic without the need for deploying and maintaining equipment in the right-of-way. In contrast to speed sensors, vehicle probes directly measure travel time using data from a portion of the vehicle stream. Commercial vehicle probe data services primarily include the use of cell phones and automated vehicle location (AVL) data.

Early demonstrations of such systems relied heavily on a single method or technology. However, services are emerging that combine information from multiple probe sources and technologies, as well as data from existing fixed-sensor networks, into a comprehensive traffic information service.

Adoption of such technologies is being driven by the high cost of deploying and maintaining fixed-sensor networks, including loop or radar-based detection. Concurrently, demand for comprehensive traffic monitoring is growing, both from travellers, who need accurate, real-time data, and transportation agencies, which need to assess the performance of the system as a whole.

The cost for gathering traffic data, either from probe-based or traditional speed sensors, is declining due to both the proliferation of technology and the emergence of businesses dedicated to traffic data collection and dissemination. Traffic data collection within a transportation agency has traditionally been application-specific and geographically constrained, such as with the need to actuate a traffic signal or collect speed and count data for planning purposes. This “stovepipe” method is being replaced by comprehensive traffic monitoring across the entire roadway system. Such an approach feeds not only legacy applications, but also supports the growing demand for advanced traveller information services (ATIS) data, such as travel time and congestion reports, and performance measurement data that assesses and improves the efficiency of existing highway operations.

AUTOMATIC VEHICLE IDENTIFICATION (AVI) TRANSPONDERS

Vehicles equipped with Automatic Vehicle Identification (AVI) transponders (example shown in Fig 15) perform a supplemental role in determining travel times between fixed points as the vehicles move across a roadway network. As electronic toll collection continues to increase, the large universe of AVI-equipped vehicles is enabling automated measurements of travel time and congestion over larger areas.

Infrastructure implemented by the motorway tolls for payment can be taken travel time data.

There are two kinds of tolls. Open tolls are those in which only the passage of the vehicle is controlled by that point, paying a fixed fare indifferently the number of kilometres. For monitoring an AVI system or the location of the bank card is used, a fact that can lead to legal problems.

Closed tolls controlled by providing a control ticket, the entrance and exit of the vehicle in the infrastructure and paying according to the journey made. To monitor these vehicles such tickets are used.

Fig 15. AVI Transponders on board a car (source: Imass DOT. Massachusetts Department of Transportation)

The readers gather real-time data to compute link travel times, average vehicle speeds, and estimate congestion from the transponders. The gather data are also used to detect incidents. An example of a toll gantry is shown in Fig 16.

The expected link travels times of vehicles are estimated using probability distributions that correspond to time intervals into which a day is divided. Under free-flowing conditions, link travel times are normally distributed. When a number of vehicles fail to arrive at a downstream reader at the expected time, the probability of an incident within the link increases, and the probability of a false alarm decreases. Frequent late arrivals increase the confidence that an incident has occurred. The number of late arrivals required to declare an incident is user specified. Once a vehicle is late, the probability that the vehicle was not delayed by an incident is decremented from one toward zero over a user-specified number of standard deviations or steps.[17]

The accuracy depends on the synchronization of clocks. The reliability depends on the volume of vehicles travelling between two tolls and that these ones do not make stops between two tolls. In the case of open toll also it depends on the vehicles do not leave the path between two control points and the number of vehicles with pagers or payment by credit card.

Fig 16. Toll gantry (source: Sirit INC)

[17] Traffic Detector Handbook. Volume I and II. Third Edition. U.S. Department of Transportation. October 2006

TRAFFIC FLOW DATA FROM CELLULAR TELEPHONES

Cell phone probes cover any method used to infer the location of vehicles by use of cell phones and their associated tower infrastructure. Methods vary between vendors and fall within two broad categories.

Signalling information, such as tower hand-off timing, is the most prevalent category, while the other category uses embedded assisted GPS technology within user phones. Whichever method is used, any cell phone approach requires a partnership with a major cell phone carrier within the region. This reliance has proven to be a critical risk factor in more than one demonstration project.

The latest technology has presented a performance, at least conceptually, similar to AVI transponders, using Bluetooth devices and antenna devices as illustrated in Fig 17.

It is a relatively new technology and its application to the ITS is still under development. However, its growing presence in personal mobile devices (mobile phones) and vehicles themselves (hands-free devices) make it a cheap vehicle detection system.

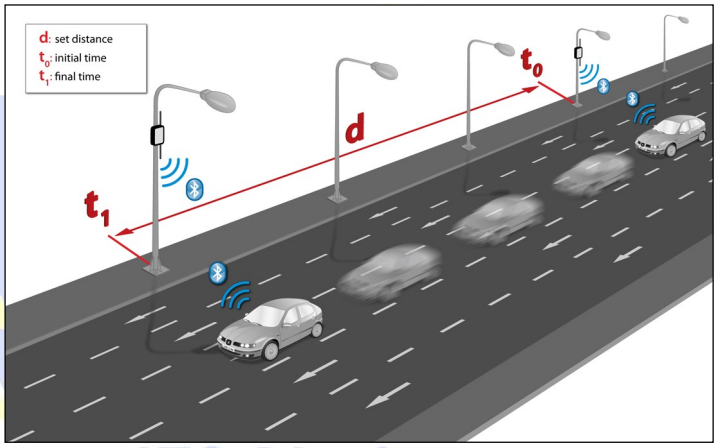

Fig 17. Speed measurement through Bluetooth (source: Libelium. Smartphone Detection)

Bluetooth wireless technology enables short-range communications focused on both mobile and fixed devices while maintaining high levels of security. Among its main advantages include its robustness, low power and low cost; if we add its high level of implementation and actual use, it becomes a very interesting technology.

Statistical sampling of the locations of cellular telephones that have their power on allows vehicles to be located in real time and, hence, supports incident detection and gathering of link travel time data on freeways and arterials. Such sampling techniques are being evaluated in the United States as illustrated in Fig 18.

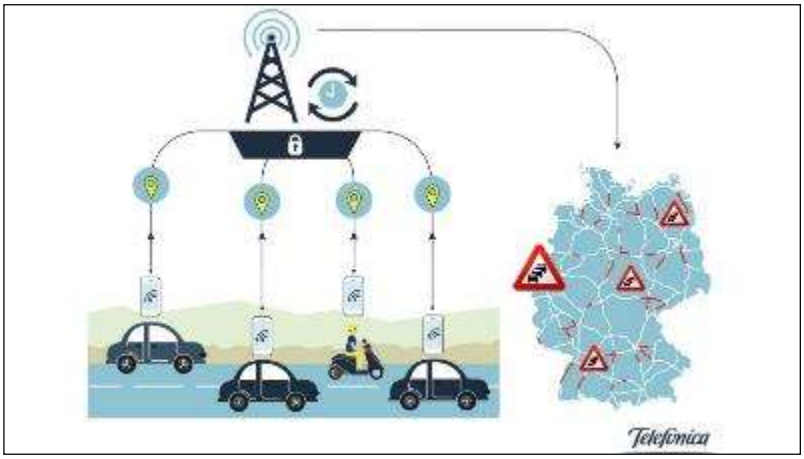

Fig 18. Example of cellular telephone utility (source: Telefónica)

Three techniques are proposed by wireless location technology and data suppliers to pinpoint cellular telephone-equipped vehicles. The first relies on direction of arrival measurements to locate the telephone signal based on its reception at two or more points. The second calculates the caller's distance from three or more receivers using time difference of arrival measurements or signals transmitted from a GPS receiver embedded in the handset of the telephone. The third scheme applies pattern recognition techniques to identify signals transmitted from the telephones to locate those in use.

However, results on lower class roadways have shown less success, cell probes have difficulty differentiating the traffic between closely spaced facilities, such as between frontage roads and the adjoining freeway. Moreover, no known cell phone demonstration to date has been able to consistently and successfully assess traffic on signalized arterials.[18]

Meteorological sensors

In addition to traffic sensors there are other important sensors for ITS systems: meteorological and environmental sensors to measure weather (fog, wind, snow, ice, rain, wind...) and conditions which may affect to the conduction (visibility, pavement temperature, road conditions, etc.).

A variety of data can be captured by meteorological information systems, such as:

- Air temperature and its humidity.
- Speed and wind direction.
- Type and rate of precipitation.

[18] Real-Time Traffic Operations Data using Vehicle Probe Technology. Stan Young. University of Maryland

TEMPERATURE SENSORS

The temperature sensors are devices that convert temperature changes into electrical signals changes that are processed by electric or electronic equipment. There are three types of temperature sensors: thermistors, RTDs and thermocouples.

For correct temperature measurement the sensor must be protected from direct exposure to sunlight and rainfall, as well as adequately ventilated. Routinely, the surface temperature is measured two meters from the ground.

In Tab 3 an example of a temperature sensor, thermometer type, and its characteristics are shown.

Tab 3. Example of temperature sensor specifications[19]

	Specification	Value
	Range	From -35 to 55 ˚C
	Precision	± 0.2 ˚C
	Sensitivity	0.1 °C
	Time constant	≤ 20 seconds

WIND SENSORS

There are two types of wind sensors: those that measure the intensity and those which are wind direction sensors. There are also solutions in which both sensors are included in the same assembly.

DIRECTION WIND SENSORS

Changes in wind direction are caused by air pressure gradients or between regions of different weather fronts. Air moves in the direction of less pressure system. Additionally, wind direction depends on many other factors such as the Coriolis effect, friction or topography. Wind direction is always given as the direction the wind is coming from.

In Tab 4 an example of a sensor for wind direction, wind vane type, and its characteristics are shown.

Tab 4. Example of direction wind sensor specifications[20]

	Specification	Value
	Sensor type	Vane with potentiometer
	Range	From 0 to 360˚
	Precision	≤ ± 5°
	Resolution	≤ ± 11.25° (32 directions

[19] UNE 199071-3. Equipment for traffic management. Roadside sensors environmental variables. Roadside sensors atmospheric variables. Part 3. Equipment

[20] UNE 199071-3. Equipment for traffic management. Roadside sensors environmental variables. Roadside sensors atmospheric variables. Part 3. Equipment

	Sensitivity	± 5° respect to a direction
	Operating temperature	From -25˚C to 50˚C

SPEED WIND SENSORS

Speed wind sensor measure accurately and produce reliable data in demanding wind conditions and climates without periodic or on-demand maintenance. Self-diagnostics and validation of measurement are standard features.

Some speed wind sensors use ultrasound to determine horizontal wind speed and direction too. The measurement is based on transit time, the time it takes for the ultrasound to travel from one transducer to another, depending on the wind speed.

The transit time is measured in both directions for a pair of transducer heads. Using two measurements for each of the three ultrasonic paths at 60° angles to each other, the sensor computes the wind speed and direction. The wind measurement is calculated in a way that completely eliminates the effects of altitude, temperature and humidity.

In addition to the ultrasonic sensor type, there is a sensor to speed wind measurement called cup anemometer type.

A relay contact output is provided for wind speed. The wind speed can be recorded either by counting the number of pulses within a fixed time period, or by measuring the time by successive pulses.

In Tab 5 an example of a wind speed sensor, ultrasonic type, and its characteristics is shown.

Tab 5. Example of ultrasonic speed wind sensor specifications[21]

	Specification	Value
	Sensor type	Ultrasonic with three sensors
	Threshold	0 m/s
	Range	From 0 to 64 m/s
	Precision	0.135 m/s in the range from 0 to 64 m/s
	Measurement type	1 second
	Operating temperature	From -25˚C to 50˚C

In Tab 6 an example of a wind speed sensor, cup anemometer type, and its characteristics are shown.

[21] Cuaderno tecnológico. Sistemas de adquisición de información de tráfico: Estado actual y futuro. Plataforma Tecnológica Española de la Carretera. January 2011

Tab 6. Example of cup anemometer speed wind sensor specifications[22]

Specification	Value
Sensor type	Three cups anemometer
Range	From 0.5 to 50 m/s
Precision	± 0.5 m/s
Resolution	0.2 m/s
Sensitivity	± 0.5 m/s
Operating temperature	From -25˚C to 50˚C

ATMOSPHERIC PRESSURE SENSOR

Atmospheric pressure is the pressure exerted by the air at any point of the atmosphere. Usually it refers to the earth's atmospheric pressure. Pressure measurement International System of Units is the Newton per square meter (N /m^2) or Pascal (Pa).

In Tab 7 an example of a pressure sensor, a barometer type, and its characteristics are shown.

Tab 7. Example of atmospheric pressure sensor specifications[23]

Specification	Value
Sensor type	Barometer
Range	From 600 to 1100 hPa abs
Precision	± 0.5 hPa
Resolution	± 1 hPa
Sensitivity	± 0.5 hPa
Operating temperature	From -25˚C to 50˚C

HUMIDITY SENSORS

The humidity is the ratio of water vapour present in the air, and that is how the measure is provided, in percent. Typically, this ratio varies inversely with the change in air temperature, so the highest relative humidity is given in lower temperatures. Normally, after dawn, when the air is heated, the relative humidity decreases. In the case of water vapour in air at 100% relative humidity is considered the case of the concentration of water vapour saturation.

There are six types of physical phenomena whose measurement allows measuring the moisture; hence there are as many types of hygrometers:

- Those which use thermodynamic methods and need to measure two temperatures (dry thermometer and wet thermometer) are called syncrometers.

[22] UNE 199071-3. Equipment for traffic management. Roadside sensors environmental variables. Roadside sensors atmospheric variables. Part 3. Equipment

[23] UNE 199071-3. Equipment for traffic management. Roadside sensors environmental variables. Roadside sensors atmospheric variables. Part 3. Equipment

- Those which measure the difference in the size of some bodies under the action of moisture (hair, twisting, carbon film ...), is called “de Saussure hygrometers” (deprecated).
- From dew condensation, which are those cooling air, enable to determine the temperature when water vapour containing in the air is sufficient to saturate it; i.e. they use the principle of the condensation of water vapour.
- The measuring water vapour diffusion through a porous medium, called diffusion hygrometers.
- Through the ability of the sensor, humidity measured by variation of chemical or electrical properties caused by absorption of water vapour.
- Finally, there are hygrometers measuring the absorption spectrum of water vapour.

In Tab 8 an example of a humidity sensor, capacitance type, and its characteristics are shown.

Tab 8. Example of humidity sensor specifications[24]

	Specification	Value
	Range	From 10 to 95%
	Precision	± 5%
	Sensitivity	3%
	Time constant	≤ 15 seconds

Environmental sensors

The environmental sensors allow measuring additional parameters to atmospheric parameters measured by meteorological sensors, important to know the state of the road and driving conditions, such as:

- Visibility.
- Temperature highway pavement.
- State of the road if it is wet or dry.
- Chemical analysis pavement.

VISIBILITY SENSORS

Visibility sensors measures optically atmospheric visibility, also known as Meteorological Optical Range (MOR), which is the greatest distance at which a large dark object (which subtends an angle of > 0.5 degrees) can be seen and recognized against a background of clear sky.

[24] UNE 199071-3. Equipment for traffic management. Roadside sensors environmental variables. Roadside sensors atmospheric variables. Part 3. Equipment

Human ability to see long distance is altered by what is known as obstruction of vision: rain, snow, fog, pollen, smoke, etc. As light propagates through the atmosphere, it is attenuated by absorption and scattering of these obstructing vision.

Visibility sensors use the principle of forward scattering. The optical system is designed so that the projected infrared light from the transmitter (TX) intersects the field of view of the receiver (RX) with a front angle. The intersection area is known as the sample volume. The signal strength received at the receiver is inversely proportional to the visibility.

In Tab 9 an example of a visibility sensor, forward scatter type, and its characteristics are shown.

Tab 9. Example of visibility sensor specifications[25]

	Specification	Value
	Range	Visibility measurement from 100 to 998 meters
	Minimum precision	± 15%
	Resolution	± 1 m
	Operating temperature	From -25˚C to 50˚C

LUMINANCE METER

The amount of light on a highway has significant influence on the quality of driving of drivers, as well as their safety. This is especially important in tunnels. How well the eye recognises vehicles and other obstacles in a tunnel depends on the lighting and visibility as well as the reflexion characteristics of the road surface and the tunnel walls. Tunnel lighting needs to be adapted to these environmental conditions. Luminance is the measure representing what a human being perceives as brightness and as such is the main control variable for the tunnel lighting.

In Tab 10 an example of a light sensor, luminance meter type, and its characteristics are shown.

Tab 10. Example of luminance meter specifications[26]

	Specification	Value
	Stability	< ± 2% per year
	Non linearity	< ± 2.5% < 1000 W/m²
	Spectral range	0.4 µm... 1.1 µm
	Time constant	≤ 60 seconds
	Response to the inclination	± 2%
	Dependence on temperature sensitivity	± 0.15% / °C

[25] UNE 199071-3. Equipment for traffic management. Roadside sensors environmental variables. Roadside sensors atmospheric variables. Part 3. Equipment

[26] UNE 199071-3. Equipment for traffic management. Roadside sensors environmental variables. Roadside sensors atmospheric variables. Part 3. Equipment