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Task 4

Autonomic functions implemented in existing ITS – status update 2019

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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 2019 update of 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 identifies 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 identifies 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.

European ITS Platform

Acronyms

AID: Automated Incident Detection

AV: Automated Vehicle

CCTV: Closed Circuit Television

DGT: Dirección General de Tráfico

DIVA: Dynamic Integrated Traffic Analysis

DRIP: Dynamic Route Information Panels

FTIA: Finnish Transport Infrastructure Agency

HGV: Heavy Goods Vehicle(s)

IMS: Incident Management System

INEA: Innovation and Networks Executive Agency

ITS: Intelligent Transport System

LAR: Local Algorithmic Response

LOS: Level of Service

NTDS: National Traffic Data System in Scotland

OEM: Original Equipment Manufacturer

PKI: Public Key Infrastructure

PSAPs: Public Safety Answering Points

RSU: Road-side unit(s)

RWS: Rijkswaterstaat

SELF-*: Generic abbreviation used to designate any kind of self-function / self-property of an autonomic system

TCC: Traffic Control Centre

T-LOIK: Integrated user interface for road traffic management

TMC: Traffic Management Centre

TMU: Traffic Monitoring Units

UPS: Uninterruptible Power Supply

VMS: Variable Message Sign

VSL: Variable 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 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 Intelligent Transport Systems (ITS) implementations and to describe the advantages and benefits of these autonomic behaviours in ITS. A first edition of the document was delivered in 2016. This is the second edition updated based on the most recent developments in the partners’ countries and the feedback received from the stakeholder engagement activities carried out after the first edition was presented.

The first step is a definition of autonomic behaviour of Intelligent Transport Systems. 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 the autonomic concept in real and existing ITS.

Finally, the third step is to define general conclusions considering also future measures and development directions for implementation of autonomic behaviour at large scale in ITS domain.

1.2. Methodology

Based on an IBM document[1] 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.

Following this, the participating partners identified and described the functions and applications which are already installed in their respective countries.

1.3. Document structure

The document has three main parts: the definition of autonomic behaviour of intelligent transport systems related to Traffic Management Centres (TMCs), the identification of autonomic functions of installed ITS 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 consider at least four high-level autonomic functions:

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

In addition, the following supporting autonomic functions should be considered:

- self-learning
- self-diagnostic

The self-management function describes a system that is able to decide automatically 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 that 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, another example, 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 a straightforward concept: 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 it is expected that major failures will still 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 failing components.

The fourth proposed function is self-configuration. It means that a system is able to adapt automatically 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

One of the most important indicators for road operator's performance is the time of response in the case of an incident or a malfunction of the system. This situation may be solved in a more optimal way if the system can take decisions and actions on its own. The autonomic functions could be the solution. Another important indicator of the performance of a 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 reduce the use of human resources in various types of incidents and to solve the problem in the shortest time. Another important benefit of the autonomic systems is the assistance of human operators 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 that the autonomic TMCs are trusted to take decisions on their own means that security is more critical and external attacks on the system need to be prevented much better than in traditional systems.

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

2.4. Benefits for society

For 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 safety related benefits are the following:

- 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 operator's speed of reaction in the aftermath of an incident and the reduction of time between the beginning of an incident and the intervention of the road operator;
- The increasing reliability of the system and increasing lifespan 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 service quality related benefits are the following:
- The decision of the system will be taken better and in shorter time;
- The general quality level of ITS services will be improved;
- The real time data as well as safety-related and sensitive data will be available at the right time and the decisions based on these data will be more accurate and responsive than the average human operator would 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.

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 cost 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 a system 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 highly qualified human resources.

The operation costs are lower than a system without autonomic implementation. The first reason for that is the decrease of human intervention in the system and the reduction of the effects of human errors. Another reason is the fact that 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. Increasing autonomy also means savings in labour costs as increasing tasks can be carried out without hiring new personnel.

2.6.2. Risk analysis

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

- Lower reliability of the system than expected and the need of human intervention
- The lack of training for this type of the system
- The lack of sufficient procedures 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 acquire tools 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 aggregated data or even automatically calculated solutions to the operator 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.

3.1. Selected functions of the Traffic Management Centre

Based on the research and activities done by experts involved in Task 4, as well as the feedback received from the stakeholders, the following functions of the TMC were selected as the most relevant for automation of operations:

- Information on unplanned events (incident/obstacles information)
- Information on planned events (roadworks information)
- Traffic time information
- Queue protection
- Line control/traffic detour
- Stationary vehicle detection
- Variable speed limits
- Dynamic Lane Management
- Temporary Hard Shoulder Running
- Ramp Management
- Weather (actual and predictions) information
- Design of traffic management plans
- Calibration of traffic management equipment/systems
- Cross-border traffic management
- Wrong way driver information

3.2. Automation scales

The following scales of automation for traffic management centre operations are foreseen from the system point of view:

- Automated module (as precursor of autonomic module) – A0

- Autonomic hardware modules – A1
- Autonomic software modules – A2
- Autonomic subsystem – A3
- Autonomic system – A4

When analysing the automation from centre operator point of view, the scales with the operator versus system roles and responsibilities could be listed as follows (Kulmala, 2017):

0. Operator makes all decisions utilizing system output and displays
1. Operator decides, but system provides recommendations (e.g. current weather controlled variable speed limits)
2. System makes decisions on actions, but operator always has a time window to interfere. In case of no decision-making capability, the systems notify the operator and just do not make decisions
3. System makes decisions, but in case it has no decision-making capability, the decision is left to the user made aware by the system of the dilemma
4. System is capable of making decisions in all situations, but the operator may take over if there is a special need
5. System is capable of and is trusted to make decisions in all situations. No operator involvement nor presence is needed

The scales from centre operator point of view are defined considering a gradual increase of the automation capabilities in sequential order of their numbering. Therefore, level 0 assumes no automation of systems so the decision is left entirely to the operator.

Moving forward, in level 2 the systems always allows a time window to interfere and it is not capable to react in all situations. In other words, it is expected to be situations unknown to the system when it no longer has decision-making capability. Level 3 is similar with level 2, the difference being that in level 3 the automation is higher and as such it is not necessary to provide a time window for the operator to interfere.

Level 5 assumes the highest degree of automation when the system knows how to react on its own in all possible situation.

The following sections provide examples of existing European TMC autonomic functions.

3.3. Traffic Control Centre Hessen

The Traffic Control Centre (TCC) Hessen is in operation 24/7. The traffic control is based on currently detected and forecasted traffic conditions, whereby the precondition is a modern, well-developed telematics infrastructure. From about 5,000 traffic sensors on motorways, extensive and updated data regarding speed, traffic volume and environmental

data are detected every minute and analysed in real-time via high-speed computer. Based on this, appropriate control and traffic management measures using dynamic telematics systems are implemented.

There are five major operations that are performed automatically at the TCC Hessen:

- Traffic Time Information Services
- Network Control Systems
- Line Control Systems
- Temporary Hard Shoulder Runnings
- Roadworks/ slot management

The following table shows the scales of automation for the different TMC functions of the TCC Hessen.

Table 3.1. The scales of automation for implemented functions of the TCC Hessen

TMC function	Scale of automation	
	system point of view	centre operator point of view
Traffic Time Information Services	A4	5
Network Control Systems	A4	5
Line Control Systems	A2	4
Temporary Hard Shoulder Runnings	A0	0
Roadworks/ Slot Management	A2	4

3.3.1. TRAFFIC TIME INFORMATION SERVICES

3.3.1.1. DYNAMIC SIGNS WITH TRAVEL TIME INFORMATION

The traffic situation and travel time are calculated automatically with the traffic model DIVA (dynamic integrated traffic situation analysis). The travel and loss times, which are generated based on the measured traffic volumes, are the basis for e.g. the dynamic signs and traffic messages, which are published online via the traffic service.

These dynamic signs as seen in Figure 3.1 are implemented on several locations in the Hessian road network.

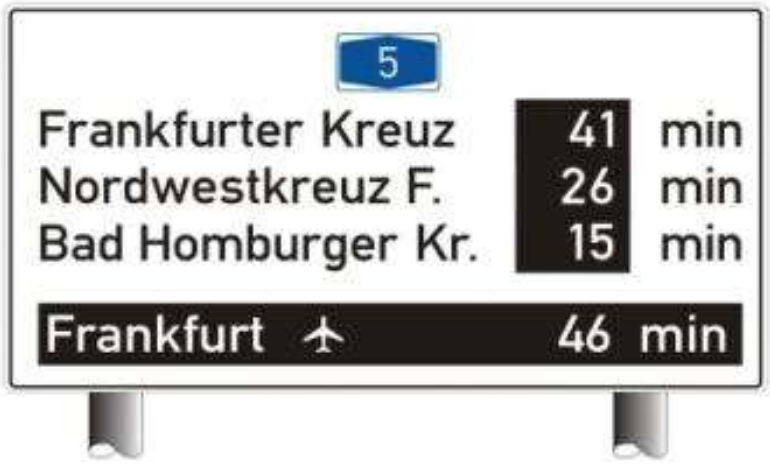

Figure 3.1. Example for a dynamic sign with travel time information (source: Hessen Mobil)

3.3.1.2. HESSEN ONLINE TRAFFIC INFORMATION SERVICE

With the Hessen Online Traffic Information Service, Hessen Mobil publishes the broad spectrum of high-quality traffic data and information to all interested road users. The Hessen Online Traffic Information Service is an information portal that supports the road-users in planning and managing their trips (see Figure 3.2).

The information is based on collected traffic data, real-time data from roadworks and up-to-date information about traffic incidents on the entire 17,000 km road network in the responsibility of Hessen Mobil.

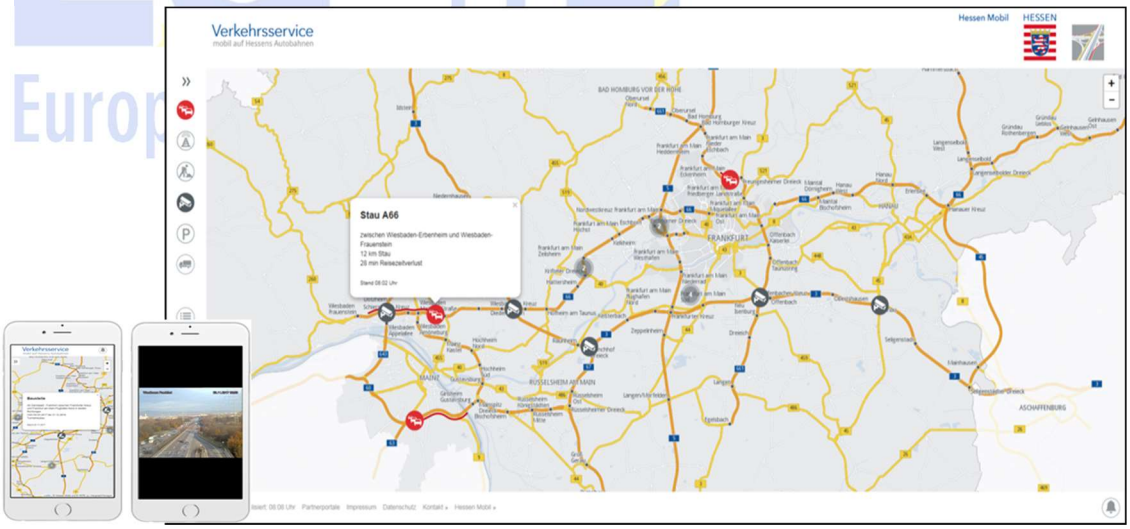

Figure 3.2. Screenshot of the Hessen Online Traffic Information Service (source: Hessen Mobil)

Following traffic information is available on the portal:

- traffic messages (congestions and closures)

- short-term road works (live tracking)
- long-term road works in field of responsibility of Hessen Mobil (current and future)
- traffic cameras (short video sequences of webcams at important decision points)
- parking spaces and rest areas (static information on location and type of facility)
- free parking spaced for trucks (dynamic information on currently available truck parking spaces)

In addition, information on the predicted traffic situation (30 min trend), e-charging stations and route recommendations has been added to the service in 2018.

3.3.2. NETWORK CONTROL SYSTEMS

Network control systems should distribute the traffic within the motorway network to avoid congestion, traffic collapse and in case of any incident. In Hessen, the close meshed road network has many alternative routes and is therefore well suited for the use of network control systems.

Beside substitutive signposting, variable message signs (VMS) are implemented at several decision points in the Hessian road network. Such VMS displays the recommendation for alternative routes, the reason for the rerouting and the travel time losses. Figure 3.3 shows an example of the displayed information.

Figure 3.3. Example of network control information (source: Hessen Mobil)

The information is generated automatically based on the current traffic situation on the road and considers the following conditions:

- time loss if it is >5 min

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

Such information makes rerouting recommendations more transparent and comprehensible for road users, which leads to greater acceptance and efficiency of the systems.

3.3.3. LINE CONTROL SYSTEMS

The use of line control equipment is an efficient way of dealing with the increasingly frequent overload on the road network. These can improve the quality of traffic flow by harmonising speeds and increase road safety by warning of traffic or environmental incidents. Currently, 300 km of Hessian's motorway are equipped with line control systems. Figure 3.4 shows an example of a line control system in Hessen.

Figure 3.4. Example of line control system in Hessen (source: Hessen Mobil)

The line control systems are operated with the Hessian control method SARAH (route control with anticipatory rule-based approach), which calculates the optimum control setting in 15-second intervals. Thus, it is possible to arrange dynamic speed limits, congestion warnings or HGV overtaking bans via VMS depending on the traffic situation automatically.

Furthermore, dynamic danger alerts (congestion warning, weather alert, broken down vehicle warning etc.) and dynamic lane management can be displayed.

3.3.4. TEMPORARY HARD SHOULDER RUNNINGS

The temporary opening of a hard shoulder lane as an additional lane tackles high traffic volume and minimises the risk of congestion caused by high traffic load in peak hours. Usually it is integrated in a line control system (see Figure 3.5). It allows dynamic signage depending on the actual traffic situation that aims for harmonising traffic flow.

Figure 3.5. Example for a temporary hard shoulder running in Hessen (source: Hessen Mobil)

In Hessen, temporary hard shoulder runnings are covering a length of around 100 km of the road network. With the hard shoulder running, the existing infrastructure is used more flexible. The specific increase in the route capacity (25% increase of the capacity on a three-lane motorway) with high traffic density avoids congestion, at the same time traffic safety is increased and the environment is protected.

3.3.5. ROAD WORKS/SLOT MANAGEMENT

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

As shown in Figure 3.6, 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.

Figure 3.6. Slot management system (source: Hessen Mobil)

3.4. Spanish Traffic Management Centres

There are many automated functions implemented in Spanish TMCs.

Table 3.2 shows the scales of automation for the different TMC functions implemented in Spain. The categorisation was based on the available documentation of the systems and the expertise from assessing the performance and impacts of the systems in practice.

Table 3.2. The scales of automation for each implemented TMC function in Spain

TMC function	Scale of automation	
	system point of view	centre operator point of view
Traffic time information	A2	4
Weather information and pollution measures signalling	A0	0
Queue protection	A2	4
Dynamic Lane Management	A2	1

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 3.7.

Figure 3.7. Traffic Management Centres in Spain (source: DGT)

3.4.1. TRAFFIC TIME INFORMATION

The main object of this tool is to provide an estimation of how much time a standard vehicle would need 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 checks whether the time criteria are met and is 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 3.8 for two sections located in A-7 and AP-7 (one for each direction).

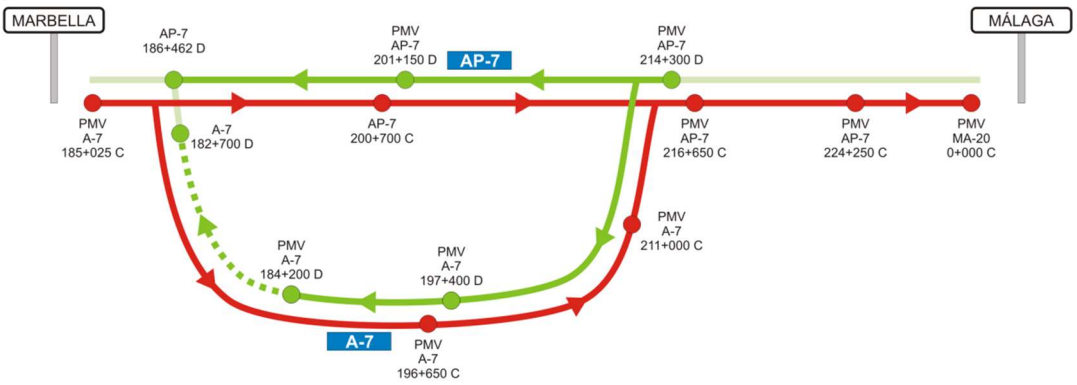

Figure 3.8. Travel times signalling between Málaga and Marbella (source: DGT, Southeast TMC)

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

Table 3.3. 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 & 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 3.4. 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 & 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 3.9.

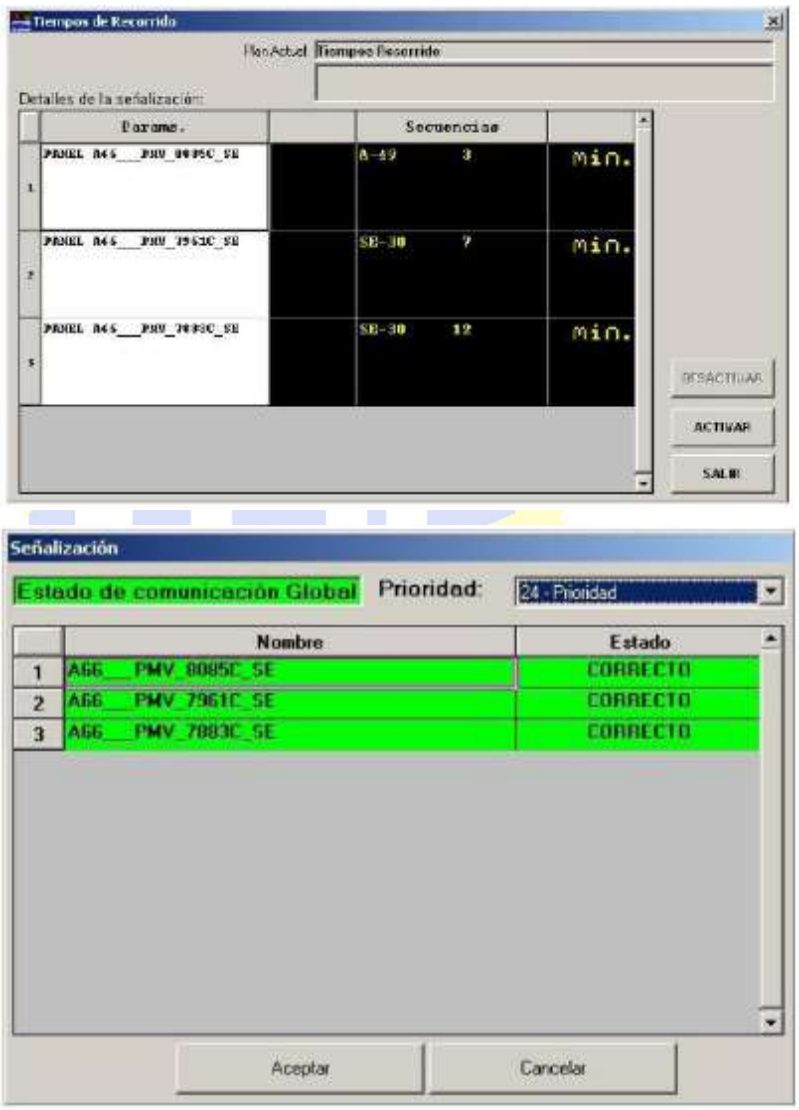

Figure 3.9. Application dialogs for travel times signalling (source: DGT, Southwest TMC)

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 one priority, only the prime one will be considered.

The interface of the application (Figure 3.10) allows making changes on the configuration, defining priorities and specific messages for each case.

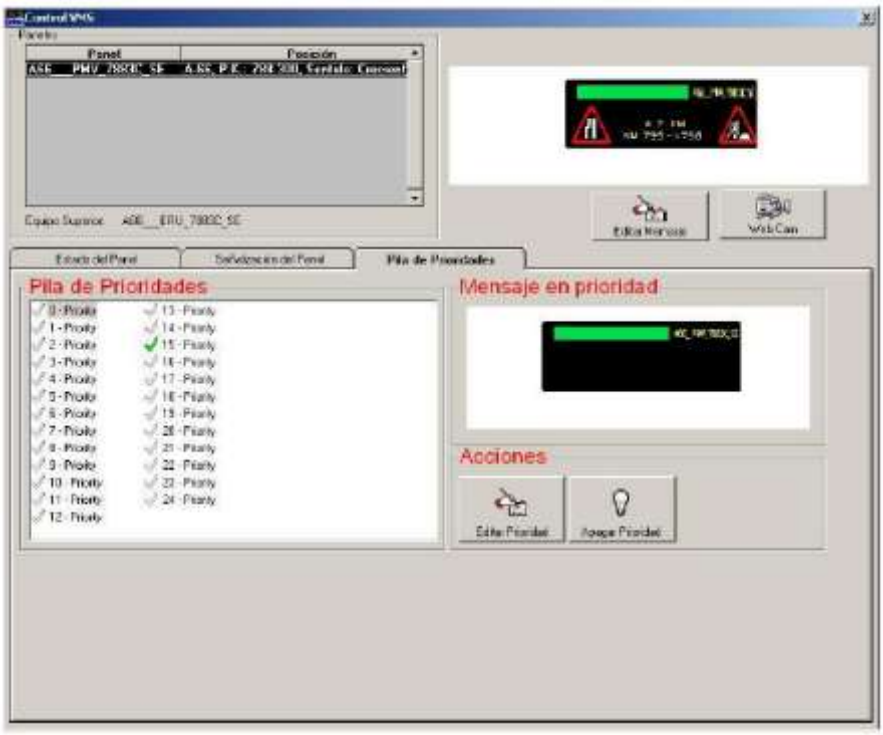

Figure 3.10. Control VMS dialoge for travel times signalling (source: DGT, Southwest TMC)

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.

3.4.2. WEATHER INFORMATION AND 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 3.11) is made considering:

- the population distribution.
- the type and distribution of vigilance air quality stations.
- the traffic infrastructure, in order to facilitate the implementation of the restrictions.

Figure 3.11. Municipal division for pollution management (source: DGT, Central TMC)

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

- 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. 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 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.
  - 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. In addition, Health Environmental Alert System will be activated.
  - 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
- 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.

3.4.3. QUEUE PROTECTION

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.

3.4.4. DYNAMIC LANE MANAGEMENT

3.4.4.1. 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.

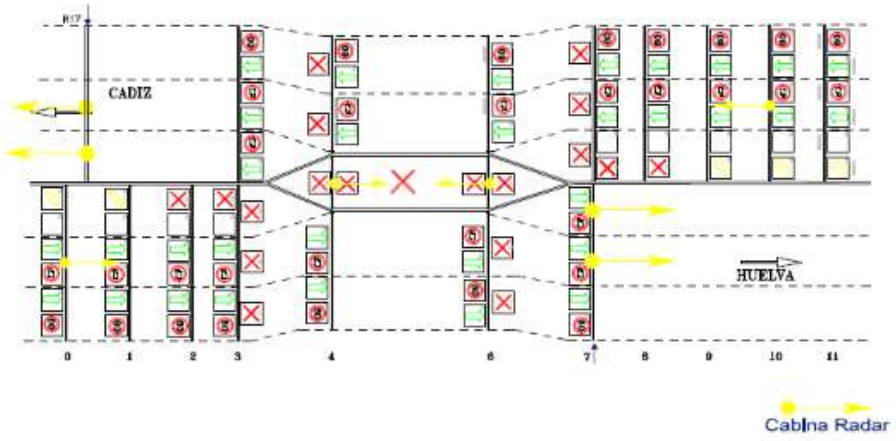

Figure 3.12. V Centenario Reversible Lane Signalling (source: DGT, Southwest TMC)

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 3.13) 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 3.13). On this dialog, it is possible to check the last status sent, as well as the user and date of signalization.

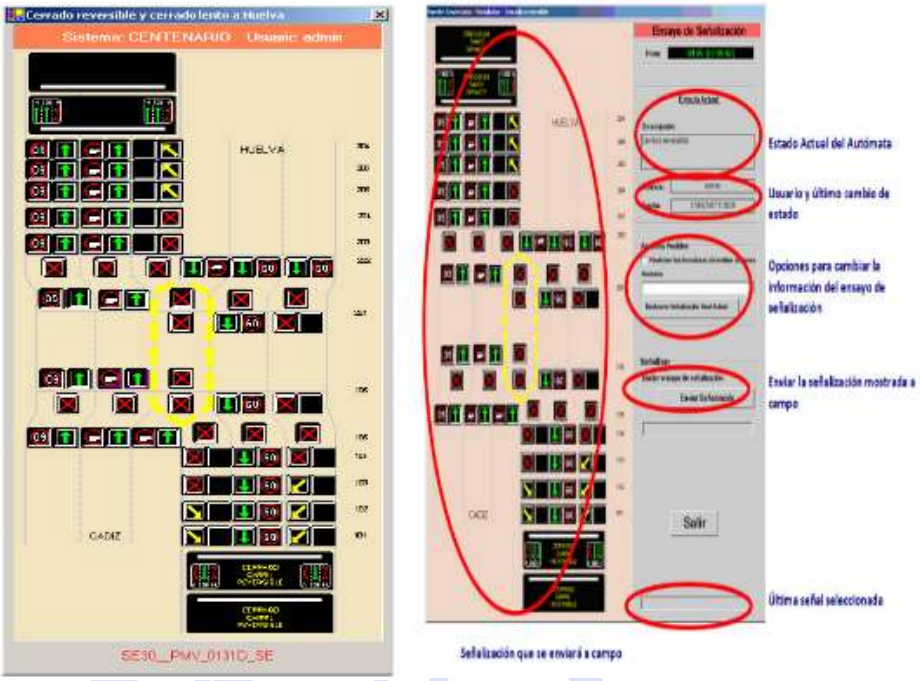

Figure 3.13. V Centenario Bridge signalization dialog (left) and test (right) (source: DGT, Southwest TMC)

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.

3.4.4.2. AUTOMATED DIVERSION SYSTEM DUE TO FOG AND/OR WIND

The Cantabrian Motorway or A-8 is a dual carriageway that extends along the coast of the Cantabrian Sea, linking the Basque Country, Cantabria, Asturias and Galicia.

Between kilometre points 545+500 and 549+500, this section of highway runs at 700m above sea level and presents two main problems: wind and lack of visibility due to fog.

The main objective of automated diversion is to reduce the time from the instant it is necessary to make the diversion or the opening of the road until it becomes effective, guaranteeing the safety of users and improving the management of the operation of the road.

The aim is to facilitate the diversion methodology, reducing the number of agents involved and therefore reducing the time required for coordination between them.

The current diversion methodology proposes to apply new technologies to send/receive information on road conditions, offending vehicles and alternative routes in real time. For this reason, various ITS equipment such as Variable Message Panels, Beacons, CCTV and Light Signalling are installed in the area.

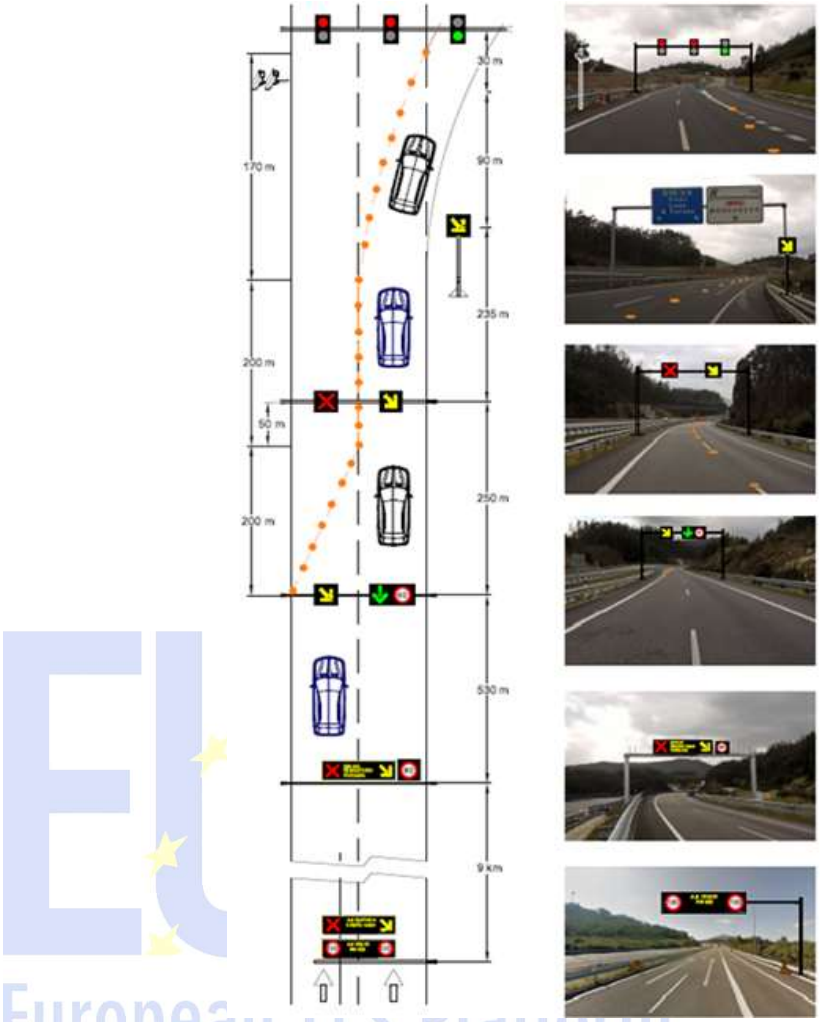

Figure 3.14. Detail of the automated detour scheme on Motorway A-8, Alto del Fiouco (Lugo) (source: DGT)

In this new methodology, the detour is automatically made from the Northwest Traffic Management Center and the steps to follow are summarized below:

- Detection: by means of the devices installed in the field (weather stations and CCTV) the level of visibility in the Northwest Traffic Management Center is evaluated and detected when the visibility in the stretch was less than 40 meters.

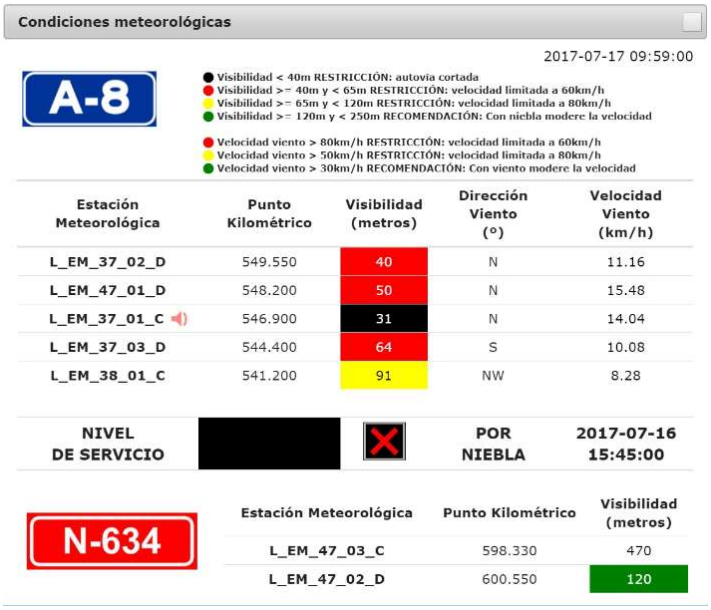

Figure 3.15. Atmospheric variable monitoring system *(source: DGT,* Northwest Traffic Management Center*)*

- Panel Signalling: Once detected deficiencies in visibility are signalled from the Northwest Traffic Management Center speed limitations or closure of the road and diversion to the N-634. Signage will be displayed on the Variable Messaging Panels installed at the beginning and end of the section. In addition, floor markers will be lit to direct vehicles.

Figure 3.16. Variable Message Signs and pavement beacons *on* A-8 Motorway, Alto del Fiouco (Lugo) *(source: DGT)*

- Tracking control: To check that vehicles comply with speed restrictions, two radars have been installed. In addition, red light photo systems have been installed at the diversion points of the motorway.

Figure 3.17. Variable Message Signs and traffic lights on A-8 Motorway, Alto del Fiouco (Lugo) (source: DGT)

3.5. 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. Some VSL sections work automatically, without acceptance of the TMC operators. These VSL sections are typically controlled by data such as a predefined time schedule.

Figure 3.18. Weather controlled Variable Speed limits (source: FTIA)

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

transmitted 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 important 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, many tunnel sections are equipped with wrong way driver detectors. A detection is based on the data by loops in the ramps before the tunnel or by AID systems in the tunnel area. The control system gives an indication of a wrong way driver in the TMC, and the operator can execute appropriated traffic control actions by using the proposed selection. When the alarm is indicated by the AID system, the action is executed automatically without acceptance of the TMC operator. The actions might be warnings on VMS and speed limit reductions.

In Finland, some tunnels have a queue protection system based on automated queue detection. The traffic control actions perform as a vehicle access control system closing the entrance to the tunnel with either traffic signals or lane control signals, and the system works independently without surveillance of the TMC operator.

A few tunnels are equipped with the slowly moving vehicle detection and sun glare warning systems. The slowly moving vehicles are detected by the inductive loops before the tunnel and the risk of glare is measured with the sensor at the end of the tunnel (glare is most critical inside the tunnel, just before the end of the tunnel). The system provides warnings of these situations to the drivers via VMS.

Travel time information is shown to the road users by the VMS and the data is accessible to service providers via an open data interface. The information is based on the data from a private service provider, and it has been aggregated for use on the appropriate road segments. The whole process works automatically.

Table 3.5 shows the scales of automation for the different TMC functions implemented in Finland. In some cases, the scales differ within a function due to the fact that the implementations differ in this respect – older implementations have less automation than more recent ones. The categorisation was based on the available documentation of the systems and the expertise from assessing the performance and impacts of the systems in practice.

Table 3.5. The scales of automation for each implemented TMC function in Finland

TMC function	Scale of automation	
	system point of view	centre operator point of view
Variable speed limits	A2	1, 3, 5
Information on planned/unplanned events	A2	2, 5
Weather information	A3	5
Calibration and diagnostic of traffic management equipment/systems	A2	5
Wrong way driver information	A2	1, 5
Queue protection	A2	5
Travel/traffic time information	A2	5

3.6. 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 Data System, Journey Time; Web and Information based services.

The following table shows the scales of automation for selected TMC functions of the Traffic Scotland ITS systems.

Table 3.6. The scales of automation for each implemented TMC function in Scotland

TMC function	Scale of automation	
	system point of view	centre operator point of view
Queue Protection and Management	A2	4
Bus Lane and Bus Hard Shoulder Running	A2	1, 3
Refuge Monitoring	A2	2
Traffic Scotland Information Services	A4	4, 5
National Traffic Data System	A4	5

3.6.1. QUEUE PROTECTION AND 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.

The queue management system closely aligned with the rules based response architecture and is a key tool in the management of the Traffic Scotland road network. 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 3.19. below). In additional

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

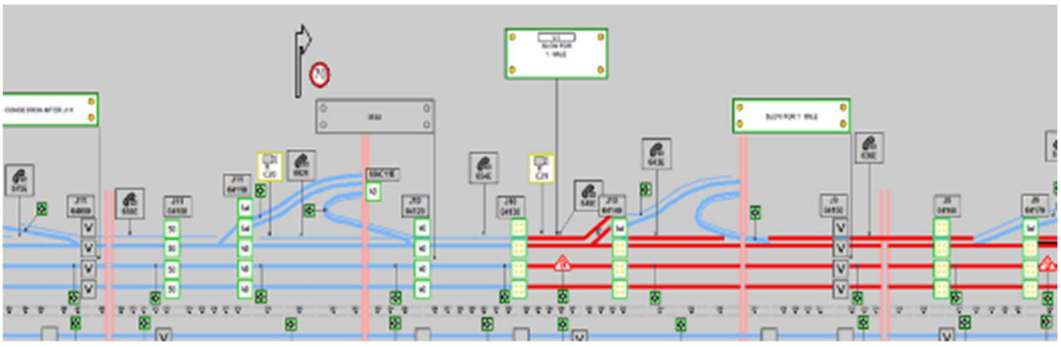

Figure 3.19. Example of Queue Management and LAR (source: Transport Scotland, IMS)

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.

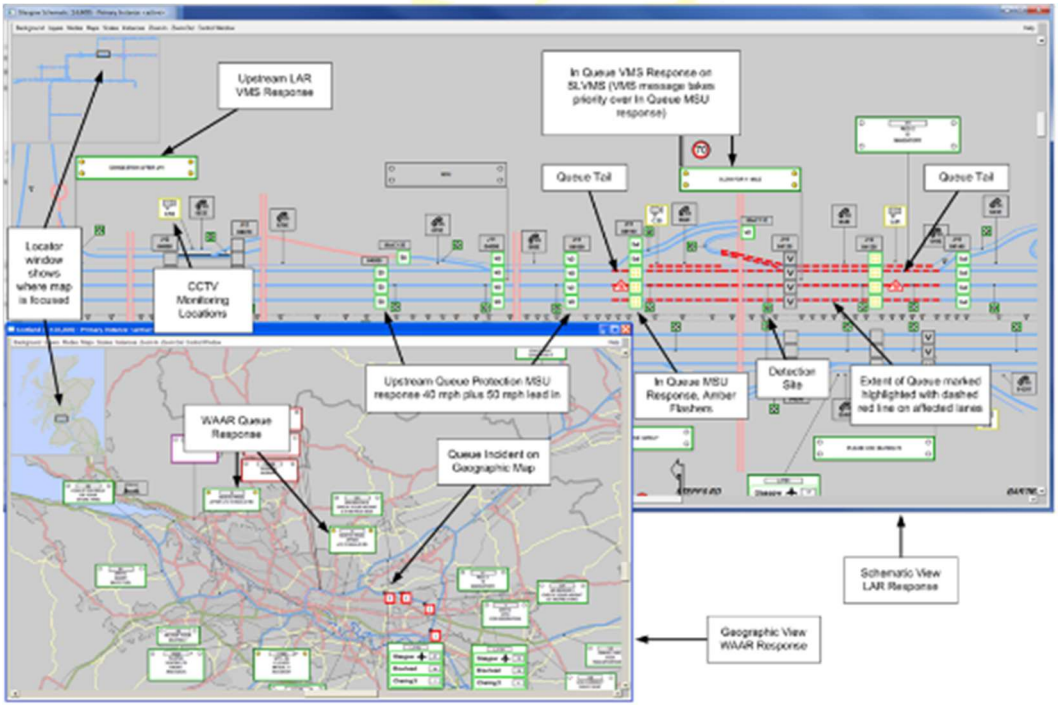

Figure 3.20. Example of Queue Management and supporting response algorithms (source: Transport Scotland, IMS)

3.6.2. 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 3.21. below.

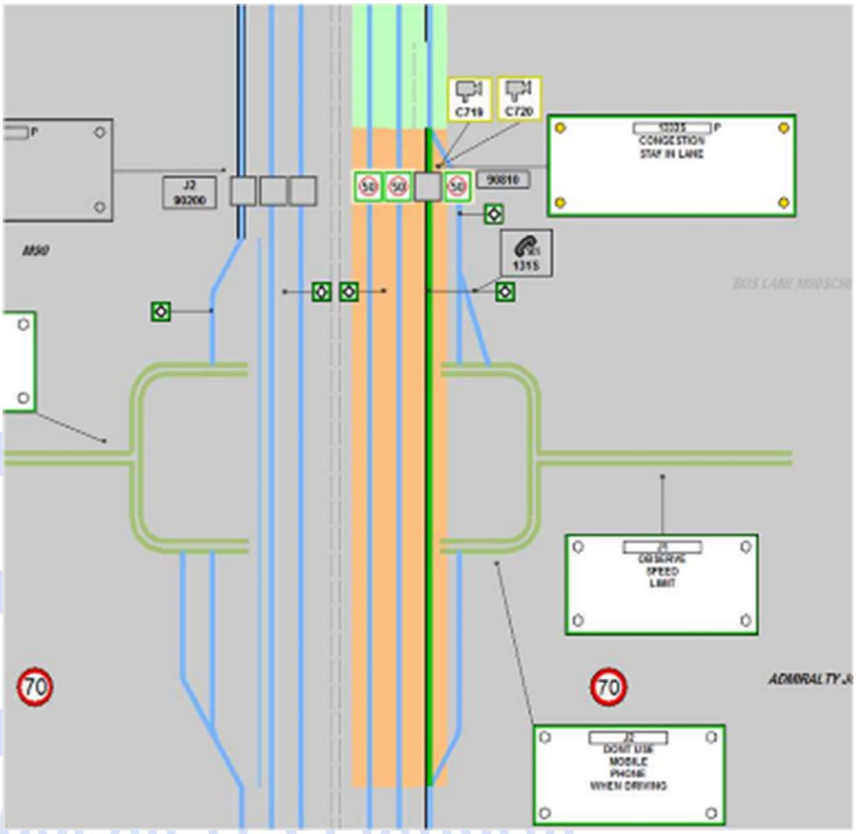

Figure 3.21. Example of Bus Lane Running on IMS (source: Transport Scotland, IMS)

The second form of Bus Lane is referred to as Bus Hard Shoulder Running illustrated in Figure 3.22. 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.

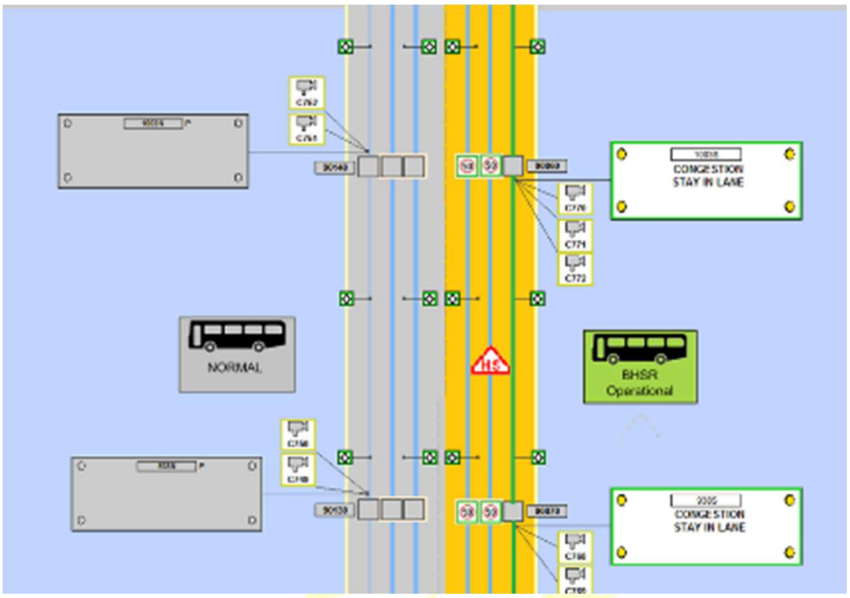

Figure 3.22. Example of Bus Hard Shoulder Running (Source: Transport Scotland, IMS)

3.6.2.1. REFUGE MONITORING

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 3.23.

Figure 3.23. CCTV control system (source: Transport Scotland)

3.6.3. 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 3.24., 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 3.25.

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.

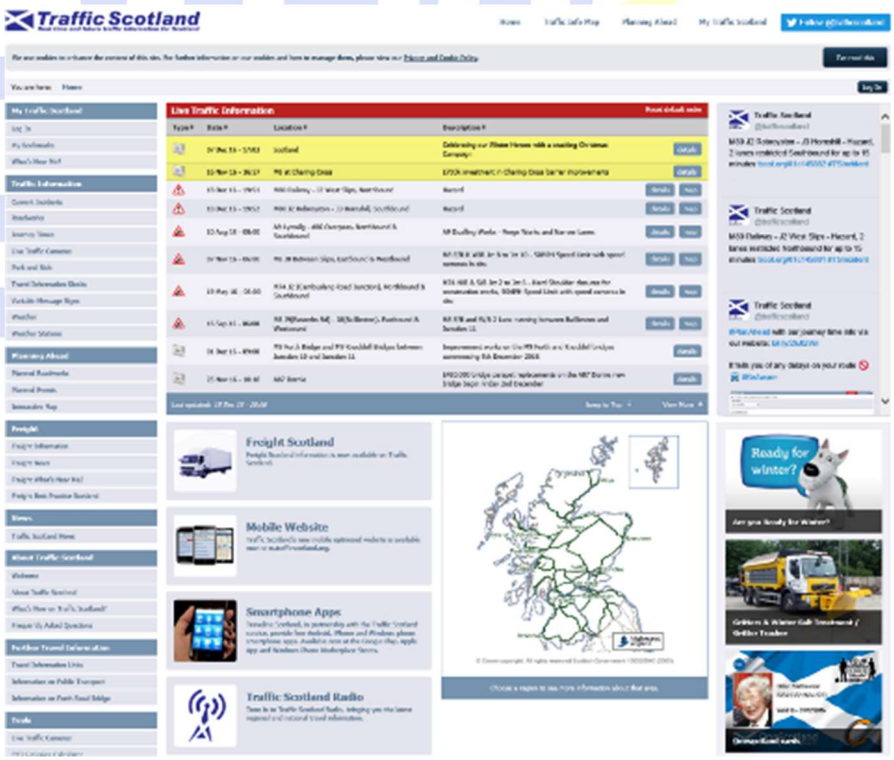

Figure 3.24. Traffic Scotland Website (source: Transport Scotland)

Figure 3.25. Example of Content Management System (source: Transport Scotland)

The system monitors traffic data, providing alarms to alert the operator to deteriorating traffic conditions or abnormal events, based on:

- HIOCC Algorithm (High Occupancy, algorithm in TMU)
- Speed (configured thresholds per monitoring site)
- Flow (configured thresholds per monitoring site)
- Occupancy (configured thresholds per monitoring site)
- Historic Flow Profile (flows outside calculated high and low thresholds)
- VMOD (Vehicle moving in opposite direction via a TMU algorithm)
- Refuge occupied (triggered by loop event caused by a vehicle entering a refuge in a bus hard shoulder running area)

Additionally the Journey Time System - which automatically collates, merges and cleanses all travel time information available to the system flexibility from a variety of internal and external sources - generates operator Journey Time Alerts. These alerts are also provided to the public via the TSIS.

3.6.3.1. *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, providing automated data storage, mining and extraction.

In light of the Scottish Government's Open Data Strategy, Transport Scotland has developed the NTDS as an open data source for traffic count data collected across the Scottish Trunk Road Network. This was done partly to satisfy Transport Scotland system requirements but also to support future opportunities arising from big data and data analytics.

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 available (https://ntds.trafficscotland.org), which is automatically updated on a daily basis.

Figure 3.26. NTDS Public portal (source: Transport Scotland)

3.7. 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 (situation January 1, 2019):

- Motorway Traffic Management System: 2781 km carriageway
- Monitoring with loop detectors: extra 1276 km carriageway
- Dynamic route information (VMS): 107 (above the road) + 337 (side of the road)
- Ramp metering systems: 123
- Traffic signal control systems: 165
- Hard shoulder running: 161 km
- Dynamic left lane: 158 km
- Lanes for trucks or busses: 331 km

The most relevant automated functions are presented below. The following table shows the scales of automation for the different TMC functions of the traffic management centres

in The Netherlands, based on expert judgement of the involved Rijkswaterstaat representative.

Table 3.7. The scales of automation for each implemented TMC function in The Netherlands

TMC function	Scale of automation	
	system point of view	centre operator point of view
Queue protection	A4	4
Variable speed limits	A4	4
(Truck) Height Warning	A4	4
Ramp Management (Ramp metering)	A4	4
Traffic time information	A4	4
Traffic flow information	A4	4
Temporary Hard shoulder running	A3	3

3.7.1. QUEUE PROTECTION

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 3.27. 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 3.27. Example of End of que warning implementation (source: RWS)

3.7.2. VARIABLE SPEED LIMITS

Variable 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.

3.7.3. (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 3.28. 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 3.28. Example of (Truck) height warning (source: RWS)

3.7.4. RAMP MANAGEMENT

Ramp management/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.

3.7.5. TRAFFIC TIME INFORMATION

Predicted travel times for alternative routes are displayed on a VMS as shown in Figure 3.29. This function is automated and based on field data from loop detectors and uses and assessment algorithm, requiring no intervention by an operator.

Figure 3.29. Example of traffic time information (source: RWS)

3.7.5.1. 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 3.30.). This function is automated and based on field data from loop detectors and uses and assessment algorithm, requiring no intervention by an operator.

Figure 3.30. Example of traffic flow information (source: RWS)

3.7.6. TEMPORARY HARD SHOULDER RUNNING

This function ensures temporary use of the hard shoulder during peak hours. Matrix signs on gantries are used to indicate whether the lane is open (green arrow) or closed (red cross) as shown in Figure 3.31.

Figure 3.31. Example of hard shoulder running (source: RWS)

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.

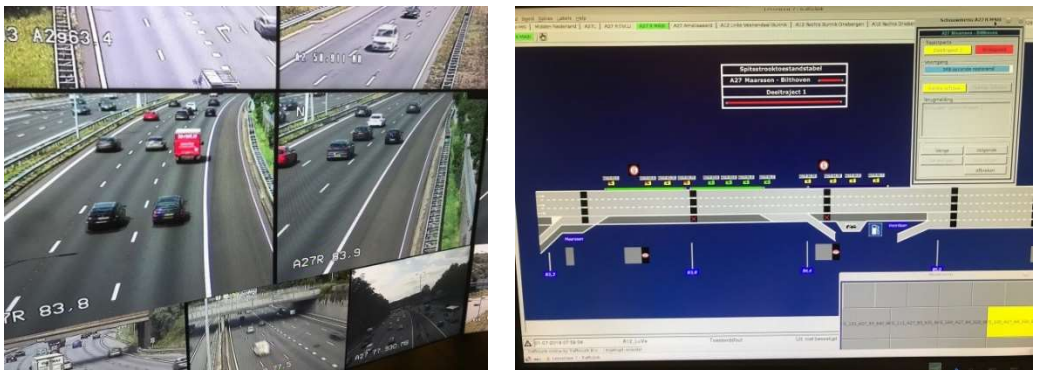

Figure 3.32. Example of the interface for managing hard shoulder running (source: RWS)

Rijkswaterstaat is currently (2019) running a trial with smart cameras; the research question is if the human visual inspection of the lanes may be automated. Cameras (and its software) would need to be able to recognize stopped vehicles and objects on the hard shoulder.

3.8. Examples of on-going national and European initiatives for automation of TMC operations

3.8.1. INFRAMIX PROJECT

The EU project, INFRAMIX, aims to prepare the road infrastructure to support the coexistence of conventional and automated vehicles, targeting to the transition period when the number of automated vehicles will gradually increase, handle the transition period and become the basis for future automated transport systems. A “hybrid” road infrastructure concept will be the project outcome after defining the necessary upgrades and adaptations of the current road infrastructure as well as designing and testing novel physical and digital elements. In order to ensure uninterrupted, predictable, safe and efficient traffic; novel technologies are designed, diverse components are incorporated, and different technologies are combined; making the demonstrations, one of the main relevant interest of the project, demonstrating the solutions developed within the INFRAMIX project in real-life conditions. The demonstrations will take place in the two test sites, in Austria and Spain, and will address all the INFRAMIX pre-selected traffic scenarios: “dynamic lane assignment”, “roadworks zones” and “bottlenecks”, including mixed traffic estimation and control algorithms.

The three scenarios, mentioned above, were chosen based on the fact that mixed vehicles share the same road infrastructure and must co-exist in the same traffic. As a result, no matter how intelligent and automated they are, or they will become, this mixed co-existence may lead to degraded traffic flow efficiency and, even worse, to new safety problems, if not managed appropriately.

Since INFRAMIX's main target is to design, implement and test both physical and digital elements of the road infrastructure as well as to ensure an uninterrupted, predictable, safe and efficient traffic through the transition period from conventional vehicles (CV) to autonomous vehicles (AV), the chosen scenarios through their implementation, should provide valuable insight to make decisions concerning challenges and ideally cover the needs for increased traffic flow efficiency and enhanced safety performance.

Based on the demonstration's requirements, physical and digital element, needs have been derived in order to specify a first high-level architecture for INFRAMIX (see Figure 3.33).

The list of components enables the interaction of different stakeholders, resulting in a hybrid end-user communication approach by using one reliable central source for traffic-estimation and traffic control strategies. The architecture solution includes the following three major stakeholders: Road Operator, Cellular Traffic Service Provider and Original Equipment Manufacturer.

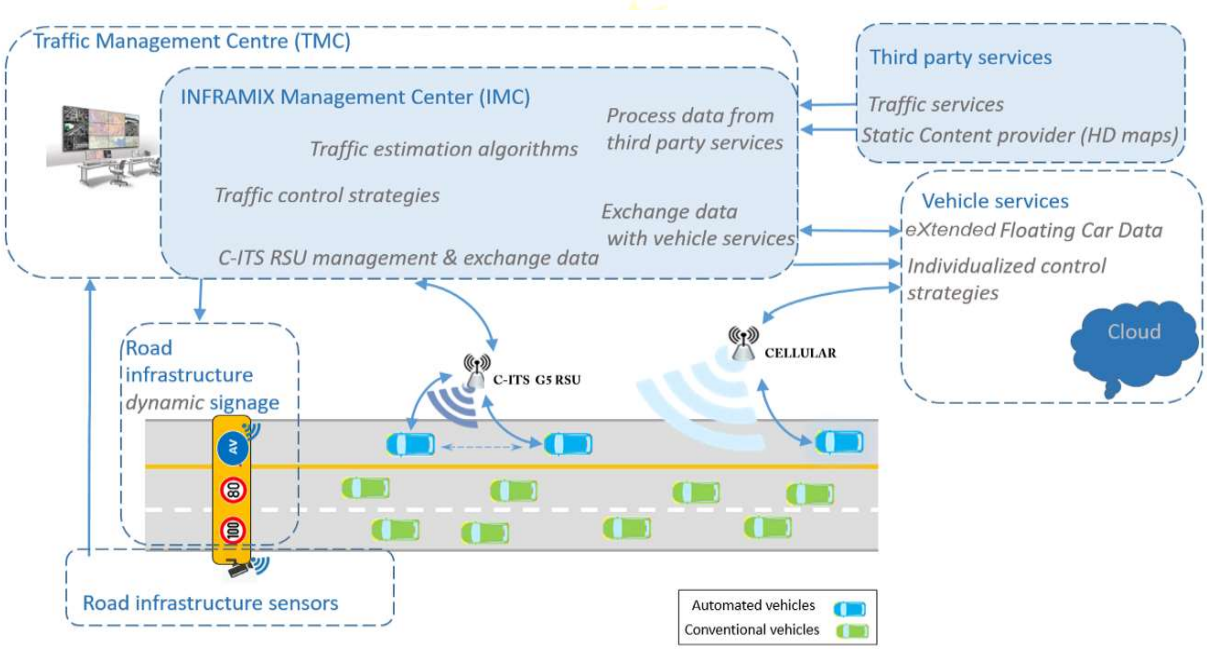

Figure 3.33. INFRAMIX high-level architecture

The collection of relevant information includes the combination of input data by road infrastructure sensors as well as digital information by connected & automated vehicles. These input data are combined and evaluated at one central source in INFRAMIX, which further performs the processing of traffic estimation and traffic control strategies. As a result, reliable traffic regulations and recommendations are developed in dependency of the current traffic situation, which gets disseminated to physical road infrastructure elements but also to interfaces of digital infrastructure elements. In result, both, conventional as well as connected (automated) vehicles, are thereby able to get informed about control-commands. INFRAMIX further supports a hybrid end-user/vehicle communication

approach, using different communication technologies. Figure 3.34 illustrates each process-stage, including its dependencies as well as its responsible contributors.
The Traffic Management applications, in order to achieve another level of integration and modernity, must offer a holistic view of a company's traffic network, allowing the use of data to support decision-making, providing detection and prediction of future trends and long-term traffic planning as well as an increase in security and regulatory compliance – for example, regarding data protection or carbon emission laws.

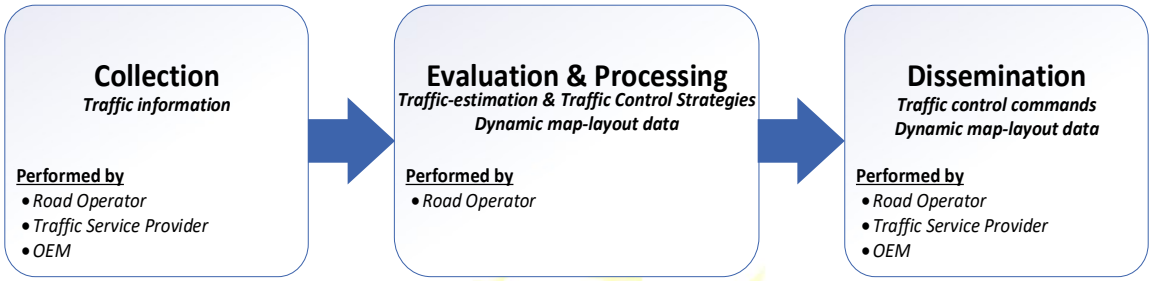

Figure 3.34. INFRAMIX process stages of the end-to-end solution

Current market trends in Traffic Management focus heavily on providing mobility capabilities, either through the creation of mobile applications for operators on the road to be able to register incidents, schedule works and maintenances or through access to the back-office of the traffic management applications either on a tablet or on a mobile phone. In particular, management access for reporting and following KPIs are being implemented more and more.

Related with the Smart Data topic, it is further important nowadays to be able to integrate information from external information sources such as V2X vehicle information, infrastructure sensor data, weather prediction, floating data and external third-party traffic data providers as well as native integration with information provided by users over social media.

The enormous data management necessary for an efficient control of operations, resources and activities requires mechanisms that allow companies to benefit from all this massive amount of data and obtain relevant information for the operators and users (see Figure 3.35). This includes, for example, Smart Data processing in real time to support decision making. The applications that most of the suppliers offer can be acquired in cloud, on-premise or in Edge Computing modes.

Cooperative Intelligent Transport Systems (C-ITS) consist in exchanging information Vehicle–to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Infrastructure-to-Vehicle (I2V) and Infrastructure-to-Infrastructure (I2I) with interoperability, multimodal and cross-border integration. The standards for these technologies are currently being defined in the European Union, and the objective is to have multi communication platforms to optimize traffic, be it through V2X communication, Internet of Things (IoT) sensors on infrastructure

or through information received from driver's mobile devices. The connected driving systems are key to the safe introduction of autonomous vehicles on daily road traffic. ITS systems will have to evolve in order to integrate the information made available from AV cars as it would from a sensor.

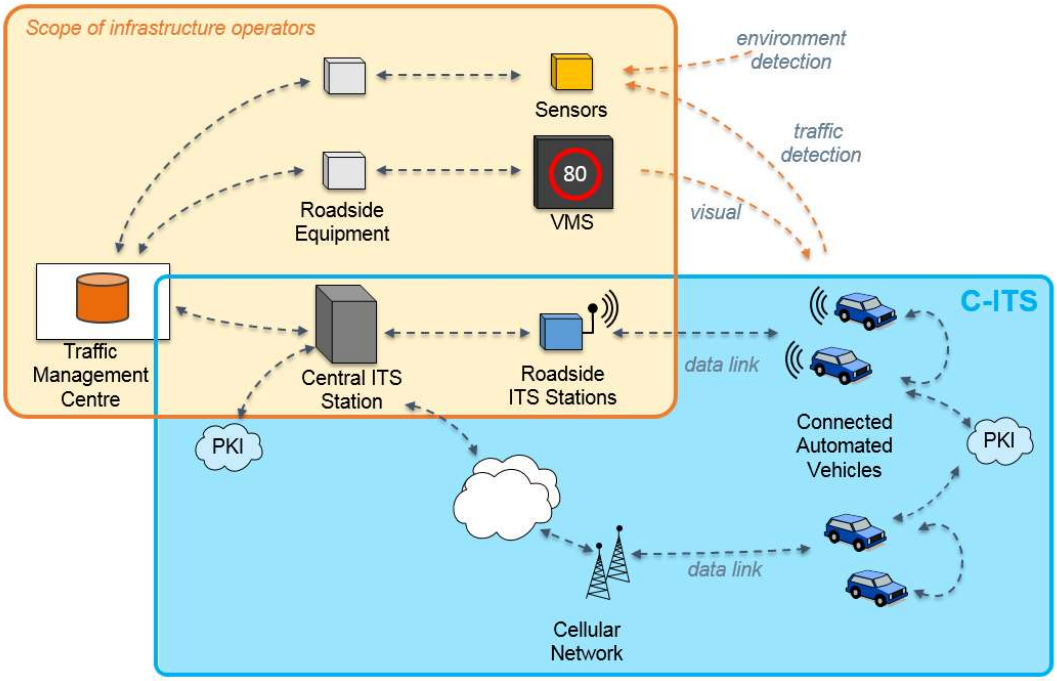

Figure 3.35. Smart Data mechanisms

European ITS Platform

4. Conclusions

4.1. Stakeholder workshop in Utrecht

EU EIP Activity 4.2 “Facilitating automated driving” held a workshop on the topic “Automation in Traffic Management and Traffic Centres: Experiences and Plans” during the EU EIP Forum on 14 November 2018 in Utrecht. The aim of the workshop was to promote a discussion on benefits of introducing automated/autonomic functionalities in the operation of the Traffic Centres.

The two workshop sessions were well attended having around 40 participants from both inside and outside of the EU EIP community, representing the industry, academia as well as road operators and authorities managing traffic centres. The presentations resulted in interesting and fruitful discussions on existing automation experiences in different European countries or projects, on ITS functions that can be automated, how to plan the automation and what KPIs can be used to assess the level of automation.

The key points resulting from the Utrecht workshop are summarized below:

- The KPIs proposed can be accepted
- The KPI “% of hardware systems with plug-and-play capability” was considered least relevant because in practice it is difficult to have truly plug-and-play systems across different manufacturers
- The KPIs “% of ratio of automated/manual road work/other maintenance operations planning per type of road” (on motorways) and “% share of correct automated actions versus all proposed automated actions” (per service) scored high initial implementation targets of 60% and 70% respectively
- The KPI “Automatically detected incidents (compared with the ones by human operators)” scored very high initial implementation target of 80% but for the particular case of video detection
- All proposed functions are relevant for automation of TMC operations
- The following new candidate functions to be considered as relevant for automation were proposed:
    - Design of traffic management plans
    - Calibration of traffic management equipment/systems
    - Cross-border traffic management
- For all the functions discussed during the workshop it was agreed that there should be automated HW and SW modules with self-* properties
- For 8 out of the 13 functions discussed it was agreed that the level can be “system makes decision”

- In case of “stationary vehicle detection” only the detection should be automated, the action is decided by the operator and the system provides recommendation
- In case of “weather information” only short-term decision-making should be automated, the long-term is decided by the operator and the system provides recommendation

Overall, the main conclusion from the workshop was that there are already experiences with automation in TMCs showing benefits such as operator workload reduction, increased efficiency in operations, increase of road network capacity and safety, and reduction of traffic delays. Also, there is potential for further advances of TMC automation in close cooperation with vehicle manufacturers. The workshop mostly confirmed the work carried out so far in Activity 4.2 and gave useful feedback for further developments.

4.2. General conclusions

This document is the 2019 update of the report first delivered in 2016. The updating is based on the most recent developments in the partners’ countries and the feedback received from the stakeholder engagement activities carried out after the first edition was presented.

The main objective of this report was to identify autonomic and automated TMC functions existing in ITS implementations. The work was carried out using input from the participating partners who identified and described the functions and applications which are already installed in their respective countries: Finland, Germany – Hessen, UK – Scotland, Spain, The Netherlands.

The description of the systems included an expert judgement of the participating partners regarding the scales of automation for each implemented function. Although there is a large variation of the values among the different systems, functions with an overall low level of automation and, on the other hand, ones with and overall high level, can be identified. For example, traffic time information scored at least 4 on the scale from the operator point of view in all implementations. In contrast, hard shoulder running scored at most 3 on the same scale, even as low as 0 in one implementation.

One of the most important outcomes of this document is the list of TMC functions that are considered by the authors as the most relevant to benefit from automation. All systems presented have automated operations for one or more of these functions. In some cases, other functions specific to the local needs (for example Truck Hight Warning or Network Control Systems) were also automated. This strengthens the general conclusion that automation is needed and brings benefits for TMCs. However, there should be a balance between automation and the involvement of human operators. In this respect, the operators should always be capable to and have the means to intervene whenever the system requires input, or when it becomes obvious that the system decision leads to a safety risk.