EU EIP SA42

Task 4

Good and bad practices from increasing the automation of road operators' ITS

Lessons learned

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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 third deliverable of Task 4 – Autonomic road side ITS systems/Automation of road operator ITS.

Task 4 will identify the requirements of automating the road operators' Intelligent Transport Systems (ITS) to facilitate the integration of automated vehicles and infrastructure. This includes roadside ITS with properties like: self-maintenance, self-optimisation, self-management and self-healing; either fully or partly based on specific needs. Secondly, the initial work plan of the task set the objective to consider good and bad practices in implementing autonomic functions on roadside and traffic centre systems. Finally, the task deals with the optimal automation level of traffic control, management and information centre operations and services.

The scope of this document is related to the objective of considering good and bad practices in implementing autonomic functions on traffic centre systems. While developing the deliverable it became evident, that focusing exclusively on selecting and presenting good and bad practices is neither beneficial nor feasible considering the lack of European-wide, mature implementations of automated/autonomic traffic management centre operations. As a result, is was decided to put more emphasis on the lessons learned from existing implementations, and to use those in order to provide useful guidelines for new implementations in the future.

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

ANPR: Automatic Number Plate Recognition

GUI: Graphical User Interface

HGV: Heavy Goods Vehicle

ITS: Intelligent Transport Systems

KPI: Key Performance Indicator

SAE: Society of Automotive Engineers

SWOT analysis: Strengths, Weaknesses, Opportunities, Threats analysis

VMS: Variable Message Sign

VMSL: Variable Mandatory Speed Limits

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1. Introduction

This chapter describes the scope and objectives of the report together with the work methodology. This report is developed as part of the work in Task 4 of the EU EIP sub-activity 4.2.

The main focus of Task 4 is to show that autonomic behaviour could be an important step in developing new intelligent transport systems (ITS) and traffic management centres where efficiency and optimisation of ITS operation, maintenance and services is the main goal.

1.1. Scope and purpose

The objective of this report is to present lessons learned from implementing autonomic functions on roadside and traffic management centre systems. In addition, a proposal for improved scales of automation of various traffic control, management and information centre operations and services will be made. The main traffic control, management and information functions will be described and a set of scenarios will be proposed to increase the efficiency based on automated and autonomic solutions. A proposal for key performance indicators (KPIs) for measuring the efficiency of automated functions in traffic control and management operations will be presented.

Automation levels widely used in control rooms (e.g. nuclear power plants) are also shortly introduced and compared to the SAE automated driving levels. Human operator tasks in different levels are highlighted in the comparison (Table 4.2).

1.2. Methodology

This report builds on the findings of the previous work in Task 4. It is mainly based on desk research and information collected from different partners about traffic management centre implementations in the respective countries.

In order for traffic management centres to fully benefit from automated operations, at least the following four high-level autonomic functions should be considered and implemented:

- self-management
    - management of the system itself
    - management of the traffic
    - management of operational activities
- self-optimising
    - optimisation of the functionality of the system

- optimisation of the resource consumption and allocation (energy)
- optimisation of integration with other sub-systems and components

- self-healing
  - recovery without any human intervention
  - updated elements
  - resilience
  - parallel processing
- self-configuration
  - hardware in the loop (virtual, near-real and real installation environment)
  - extension of the system
  - geographic configuration
  - integration with other systems
  - customisation of the system

Also the following supporting autonomic functions should be implemented to achieve more reliable and advanced traffic management operations:

- self-learning
  - self-learning in operation of the system
  - self-learning in function of the system
  - self-learning in decision making process and integration with other systems
  - self-learning in security
  - self-learning in autonomic functions
- self-diagnostic
  - support for self-healing
  - support for self-optimisation

A table template was used to collect information from the partners about current implementations of automated functions in traffic management centres. The template contained three sections:

- a short description of the presented functions

- a checkbox list for indicating which of the autonomic functions the described system implements or is related to
- a description of the main results and lessons learned from implementing the specific system.

1.3. Document structure

This report is divided into four main parts. First, chapter 2 presents identified practices and lessons learned from implementing automated and autonomic functions in existing traffic management centres.

Secondly, chapter 3 discusses how to increase the efficiency of traffic management centre operations and proposes a selection of functions to be considered for automation in the early stages of system implementation.

Chapter 4 deals with defining scales of automation from different perspectives.

Finally, chapter 5 proposes a number of key performances indicators that can be used to assess the benefits of increasing the automation of traffic management centre operations.

2. Identified practices of implementing autonomic functions

This chapter presents a number of identified practices from different traffic managements centres that have implemented systems with automated and/or autonomic functions. For each system, a brief description is given as well as the main reasons for considering it as a relevant example of implementation.

2.1. Traffic Information Systems

<table>
<tr><td colspan="2">Country: Germany (Hessen)</td></tr>
<tr><td colspan="2">System: Traffic Information Service (www.verkehrsservice.hessen.de)</td></tr>
<tr><td rowspan="2">In 2016, Hessen Mobil has launched the Traffic Information Service which is applied for the internet and smartphones. Using this traffic service portal Hessen Mobil has the possibility to offer road users a broad spectrum of high-quality traffic information which are prepared optically new and appealingly. The new web page is responsive and can adapt resolution and display to each end device. Within this portal the following information regarding the Hessian motorway network can be provided for the road users:
- Short and long term road works
- Congestion
- Closures
- Truck parking
- Parking and rest areas
- Video clips
The data are generated in the Traffic Control Centre automatically and available via technical interfaces.</td><td>Autonomic function(s) it relates to:
☐self-management
☐self-optimizing
☒self-healing
☒self-configuration
☐self-learning
☐self-diagnostic</td></tr>
<tr><td>Main results identified:
- Automatic provision of user-friendly information
- Provision of actual and reliable information for road users
- Regular usage by the residents
- Acceptance by the users
- High binary rate of data</td></tr>
</table>

Country: Finland	
System: T-LOIK System	
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. The following information can be provided by T-LOIK for the road users: - Road weather - Traffic volume and congestion - Travel time - Incidents - Road works - Events	Autonomic function(s) it relates to: ☒self-management ☐self-optimizing ☐self-healing ☐self-configuration ☒self-learning ☒self-diagnostic Main results identified: - Automatically updated open data for service providers - Automated traffic information based on automated traffic status data - Automated information dissemination from traffic centres as soon as the operator has typed in the information - Towards automated short-term prediction and informing about the predictions The most important results/impacts of the increased automation are the improved data flow from traffic management centre to the road users.

2.2. Traffic Management and Control Systems

<table>
<tr><td colspan="2">Country: Germany (Hessen)</td></tr>
<tr><td colspan="2">System: Network Control System</td></tr>
<tr><td rowspan="2">The network control is a combination of information and management through recommendation to distribute the traffic within the motorway network. Therefore, the estimated travel time of different routes is compared. If the time loss is higher than a defined threshold, rerouting programs are started automatically to generate the recommendations on the dWiSta-VMS (Variable sign-postings including congestion warnings and travel time information).
To manage and to control the complex network by one system automatically a modern graphical user interface (GUI) was developed for core components in Traffic Control Centre Hessen. The GUI can control dWiSta based on travel time and delay time automatically. Operators can also activate and control special programs manually, e.g. in case of full closures and planned re-routings. In the future, dynamic signposts will be integrated into the GUI.</td><td>Autonomic function(s) it relates to:
☐self-management
☒self-optimizing
☐self-healing
☒self-configuration
☐self-learning
☒self-diagnostic</td></tr>
<tr><td>Main results identified:
- No manual interference necessary
- Integration of more variable message signs possible because of the flexibility of GUI
- Temporary diversion could lead to new congested routes
- Routing recommendations depend on the overall situation and loss of travel time (> 10 min)
It is necessary to check the routing recommendations before setting up a roadwork</td></tr>
</table>

Country: Germany (Hessen)	
System: Strategy Management – Intermodal/Interregional Strategy Manager (ISM)	
To manage incidents that effect the traffic cross state border, a strategy management is applied to plan and implement coordinated measure bundles in different responsibility areas. Initiated by Hessen Mobil in 2005, the LISA initiative aimed at the development of standardised technical and organisational procedures, in order to control the traffic on motorway network in cross-border corridors in Europe, but especially in Germany. To support the strategy applications for long distance corridors, the web-based tool "Intermodal/ Inter-regional Strategy Manager (ISM)" was developed. The ISM is used for the web-based strategy coordination between different traffic control centres to automate the following processes: - Traffic situation analysis for problem detection - Selection of suitable strategies - Request to involved partner regarding activation of preselected strategies - Monitoring of activated strategies online - Activation/Deactivation of measures based on selected strategies The concept is based on a local coordination approach, i.e. each involved partner is responsible for problem detection, strategy development and implementation of measures in its own responsibility area. In advance, the possible strategies are evaluated and coordinated by all partners. The ISM documents the strategy exchange and delivers a strategy catalogue for all partners.	Autonomic function(s) it relates to: ☒self-management ☒self-optimizing ☐self-healing ☐self-configuration ☒self-learning ☐self-diagnostic Main results identified: - Automating processes of strategy coordination between different responsibility areas is possible - Remaining responsibility (e.g. for problem detection) is in the own responsibility area of partners - Flexibility of ISM by web-based approach

Country: Germany (Hessen)	
System: Line Control System	
The line control systems should harmonize traffic flow on the motorways. The systems are controlled via the method called SARAH (Streckensteuerung mit antizipierendem regelbasierten Ansatz in Hessen) which was developed in Hessen. With SARAH following automated processes can be considered: - Variable speed limits for harmonisation of traffic flow - Speed reduction and danger alert at congestion tailback approach - Lane closures for safeguarding of roadworks and accidents - HGV overtaking ban The automatic programmes (except HGV overtaking ban) will be activated based on thresholds related to the lanes. The operators still have the opportunity to intervene in case of accidents and safeguard of road works manually. At the moment, the data detected and used for SARAH will be analysed regarding environmental aspects (air pollution and noise) if this data can be used as additional control criteria.	Autonomic function(s) it relates to: ☒self-management ☒self-optimizing ☒self-healing ☒self-configuration ☐self-learning ☒self-diagnostic Main results identified: - Automatic control of line control systems including several processes - Less intervention by the operators is necessary - Possibility to add further control criteria - Gain of a traffic flow by variable speed limits - 20 % to 25 % decrease of accident costs - 10 % increase of road capacity - Control based on transparent criteria, so that each switch is justified in terms of road traffic regulations

Country: Germany (Hessen)	
System: Temporary Hard Shoulder Running	
The hard shoulder can be used as an additional lane to cope with high traffic volumes at peak times on several Hessian motorways temporarily. The opening of hard shoulder is triggered by operator based on the current traffic situation. The operator starts the camera observation, which is conducted automatically by the camera. After the video approval by the operator, the hard shoulder will be opened section by section. After the opening, the hard shoulder is video-supported observed permanently. In case of occurred incidents or lower threshold of traffic density, the hard shoulder will be closed, triggered by the operator. A manual intervention of the operator is possible at any times.	Autonomic function(s) it relates to: ☐self-management ☐self-optimizing ☐self-healing ☐self-configuration ☐self-learning ☒self-diagnostic
	Main results identified: - Gain 25 % in capacity of a three lane motorway - Traffic density and thus travel speed as indicators for the opening - Opening when a congestion occurs in the road section in front - Closing by monitoring the section itself and when traffic density is low or an accident has occurred at the hard shoulder - Automatic detection of failed components - Permanent video observation of hard shoulder is necessary

Country: Germany (Hessen)	
System: Slot Management for Road Works	
The slot management system checks automatically if the transport system can handle a roadwork and determines suitable time slots for projected works on motorways. Therefore, possible time slots for any planned short-term roadwork 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 by the user, the system calculates possible time slots based on traffic data, expert knowledge and rules. These time slots will be presented in green. Time slots which are marked in red cannot be selected due to the risk of congestion on the motorway. The green times slots can be blocked manually due to planed events (e.g. during the International Automobile Fair).	Autonomic function(s) it relates to: ☐self-management ☒self-optimizing ☐self-healing ☐self-configuration ☒self-learning ☐self-diagnostic Main results identified: - Automatic calculation of optimal time slots for road works - Calculation based on several data sources for an easy handling - All roadworks are assessed in terms of traffic impact

<table>
<tr><td colspan="2">Country: Spain</td></tr>
<tr><td colspan="2">System: Automated traffic detour in A-8 motorway (O Fiouco)</td></tr>
<tr><td>Since December 2016, an action protocol for reduced visibility has been implemented in A-8 Motorway. The main feature of this protocol consists on the automated deviation of traffic flow or even the closure of the road when the visibility reaches determined ranges of low values because of the dense fog.</td><td>Autonomic function(s) it relates to:
☒self-management
☐self-optimizing
☐self-healing
☐self-configuration
☐self-learning
☐self-diagnostic</td></tr>
<tr><td>For the proper functioning of the automated detour, it was necessary to install multiple ITS devices (Weather stations, VMS, cameras, beacons, etc.) to inform and detect in real time all the actions that are taking place on the road.

The methodology followed in this protocol can be summarized on the following points:

- Detection of visibility values by weather stations.

- Acceptance of this information and activation of the restrictions by traffic operators according to the visibility values.

- Signalling the restrictions by VMS in order to inform road users and guarantee their safety.</td><td>Main results identified:
- Improvement in road safety by reducing the average time between the detection of the risk and the implementation of the safety measures.

- Resource and time optimization, replacing field operators by remote ITS devices.
- Good acceptance by road users and better results obtained since its implementation</td></tr>
</table>

Country: UK – Highways England	
System: Stationary Vehicle Detection System	
A key technology in the system is the tracker. It follows multiple hypotheses for each sequence of radar measurements, and fits them to different movement models and signal power models for people, vehicles and debris. A ‘track’ is the processed information, for each object, and includes the location, direction, size and speed amongst other information. The tracker maintains many potentially valid tracks in the background, but only goes on to pass them on to the next stage in the processing chain when they pass a ‘likelihood’ criteria. The valid tracks, generated by the tracker are passed to an alarm generation process. At this stage, alarm signals are raised should a track break a series of business rules. For example, if a tracked vehicle speed falls below a threshold, for more than a defined period of time an alarm will be raised, i.e. a vehicle is tracked at a speed of less than 5 kph for more than 10 seconds. In this way, the track can be generated and followed for several seconds to confirm that it is valid, before an alarm is raised. Alarms for people, debris or reversing vehicles are similarly raised with different business rules used for the alarm generation.	Autonomic function(s) it relates to: ☐self-management ☐self-optimizing ☐self-healing ☒self-configuration ☐self-learning ☐self-diagnostic Main results identified: - the system reduces surveillance load of continuous watching CCTV monitor - processing chain algorithm only escalates to the alarm generation process when the likelihood criteria are passed, this lowers the false alarm rate - system can detect different stationary objects, uses different business rules for each - statistical analysis of events can be made using the stored data

Country: UK – Transport Scotland	
System: Automatic Queue Protection and VMSL (Variable Mandatory Speed Limits)	
The real time level of congestion reported by traffic monitoring units via MPC's is used by the incident management system to automatically set appropriate primary response on the nearest upstream lane control units. Lead-in values are set upstream to gradually reduce speed of upstream traffic. Dependent on congestion levels the incident management system can set VMSL between 20 and 60 mph, however during high congestion conditions a 40 mph primary setting is implemented by McMaster queue detection. With correctly configured settings VMSL will respond using 50 to 60 mph speed limits before McMaster queue response is triggered to attempt to defer the onset of traffic breakdown.	Autonomic function(s) it relates to: ☐self-management ☐self-optimizing ☐self-healing ☒self-configuration ☐self-learning ☐self-diagnostic Main results identified: - Algorithm has 'update factor' allowing for the position of the curve to alter based on current flow patterns and respond to changes in traffic state by considering occupancy value on the motorway. The update factor is useful when weather conditions change quickly. For example, a sudden downpour will cause the curve to move away from the data slightly so that false queues are not raised as traffic slows down because of the weather. - VMSL aspects are set automatically, no need for operator intervention - VMSL reduces / raises speeds incrementally in 10 mph steps, safety is always the primary focus

Country: France	
System: Lane and ramp management for the A50 in the tunnel under the city of Toulon	
Tunnel safety regulations ask for traffic management strategies that prevent congestion to settle in a tunnel. For the tunnel under the city of Toulon, France, the designed solution involves a complex algorithm, called Stratified Zone Metering, that aims at minimizing the congestion inside the tunnel through ramps metering and management of motorway lanes before the tunnel. Three ramps are managed by the system after the tunnel, one being a double insertion. Individually for each ramp, the algorithm compute and update the traffic light signal cycle every 40s based on the traffic data and the desired insertion flow. It also takes into account the queue at each ramp and try to avoid spill back onto the urban road network. For lane management before the tunnel, the algorithm evaluates the opportunity to reduce the motorway capacity by computing the effect of a lane closing (it can close one or both). Doing so is only a second line options, since closing one or two lane has a huge effect before the tunnel. The algorithm takes into account the data from the ramp sensors and the expected flow in case of ramp emptying (to avoid spill back on the urban network). When a lane closing is suggested, the system propose the action to an operator that can validate or refuse it. If the action is validated, the system then engages a scenario of actions and play it until the goal (closing one or two lane) is completed.	Autonomic function(s) it relates to: ☒self-management ☒self-optimizing ☐self-healing ☐self-configuration ☐self-learning ☒self-diagnostic Main results identified: - the system is able to present summary of situation to operators and propose actions based on the complex algorithm and multiple input that have to be taken into account thus saving the operators the time they would have needed to make sense of the data. - due to its urban environment, the system is able to react at a more suitable pace than a human, for each of the metered ramps. It can for instance decide very quickly to empty or hold a ramp queue.

3. Increasing the efficiency of traffic management centre operations based on automated and autonomic solutions

3.1. Expected effects of automation

Traffic management centres are operating in environments where the volume of data is rapidly increasing. As a result, greater computing power is necessary to collate, analyse and interpret data in an effective and timely manner. Generally, as the scenario of automation increases, the cost of design and development of highly efficient algorithms increases, the time to develop the system increases, as do the benefits. Each automated system will have a set of benefits, but general benefits of automating ITS include:

- Manpower savings (reduced need for human intervention in low level systems, e.g. monitoring, diagnostics and scheduling)
- More cost effective 24/7 operations
- Increased safety (e.g. automatic incident detection, queue protection algorithms and response management techniques)
- Reduced operator workload, frees resources to work on higher priority and higher added value tasks
- Time savings (e.g. large scale data collection, faster processing and analysis / assessment)
- Network efficiency (e.g. variable speed limit and ramp metering to reduce flow breakdown and maximise throughput)
- Increased decision making capacity (reduces human information overload, the ability to solve multiple traffic management tasks simultaneously)

As the tasks in the traffic management centres increase and become more complex, there is a need for more operators. However, in most cases there are budget constraints and it is not possible to hire more people. In this situation, increasing automation of the operations with self-management and self-optimising functions can decrease the required operator workload and increase the efficiency of service provision.

In case of malfunctions, automated functions (like self-diagnostic or self-healing) can contribute to faster reaction times and minimize the down-time of operations.

Introducing automated and autonomic functions for data collection/update and for traffic information provision can reduce the effort for human operators. It can also increase the efficiency of the operations as a whole.

3.2. Selected traffic management and information functions

The practices presented in Chapter 2 offer a good image of existing level of automation in centres and the benefits it can bring to the operations. They cover operations related to providing information to road users and operations for traffic management and control. The previous deliverable of the task defined a functional architecture of an autonomic traffic management centre at a more abstract level. Taking into account these functions and the presented practices, we propose a subset of functions to first be automated (Table 3.1). The functions were selected because they were considered to bring the most significant benefits in the early stages of automating traffic management centre operations.

Table 3.1. Selected traffic management and information functions performed by the traffic management centre

Reference to functional architecture	**Connected traffic management centre operations**
Provide traffic information to the user	Unplanned events: incident/obstacles information
	Planned events: roadworks information
Provide traffic control	Queue protection
	Line control/traffic detour
	Stationary vehicle detection
	Variable speed limits
	Dynamic Lane Management
Manage demand	Temporary Hard Shoulder Running
	Ramp Management
Provide environmental information to the user	Weather (actual and predictions) information

3.3. Scenarios for increasing efficiency

Autonomic applications can be considered as multi-layered, with integration of the layers building automated components into an overlapping autonomic system. In this section, the following scenarios for introducing automation are proposed and the expected benefits for traffic management centre operations are discussed:

- **Minimum system update**: automation of only hardware components/modules.

  This scenario could include the implementation of system with a single automated function, for example an automatic number plate recognition (ANPR) system with self-diagnosis capability that alerts the traffic management operator if a drop in capture rate performance is detected, or the implementation of self-configuring / "plug and play" system components reducing the need for local set-up and configuration.

- **Medium system update**: automation of hardware components/modules and automated data collection/information provision for some operations.

  In this scenario automated components/modules are combined, these could include:

  - Automated fault management and maintenance systems to collate diagnosis and fault information from field equipment, determine and propose optimised repair schedules.
  - Roadworks scheduling and booking software to avoid resource conflicts and forecast completion.
  - Traffic management measures, such as coordinated traffic responsive ramp metering, hard shoulder running and variable speed limit algorithms.

- **Significant system update**: automation of hardware components/modules, automated data collection/information provision for some operations and operations with self-management characteristics – actions are calculated and proposed to the operator.

  This scenario reflects a more complex, large-scale integrated traffic control system where the modules / sub-systems of traffic detection (e.g. inductive loops, ANPR), management (e.g. variable speed limit, ramp metering) and information (e.g. VMS, traveller apps) are connected and actions can be proposed by the system based on the current and / or predicted conditions. For example, in the event of an incident an automated alert from a queue protection system is signalled in the traffic management centre, the system can propose the lane closure pattern, supporting information messages on VMS in the vicinity, and appropriate reduced mandatory speed limits. These proposals are then accepted or rejected by the operator.

Looking further into the future, it could be possible for the traffic management centre operator to define the desired outcome based for example on a vehicle emissions target or throughput, and the system would analyse and implement the measures required to achieve the target. With increasing self-management, the system would be able to carry out and monitor the execution of the plans, and learn and adapt from experience.

The above automation scenarios and scales of automation from the operators' perspective are described further in section 4.1.

4. Defining the scale of automation in traffic management centre operations

4.1. Scales of automation for traffic management centre operations

Implementation practices analysed in this report and in previous ones show, that automation of traffic management centre operations is needed for road administrations, and that it is already implemented in various degrees depending on the context of use, available resources, and traffic management needs. At the same time, it is obvious that the increase of automation towards full autonomic systems has to be done in incremental steps, and that it will take several years and a lot of testing for it to reach maturity. An implementation roadmap up to 2025 was proposed in the deliverable “Needs for autonomic functions in road operators' ITS” that follows an approach from hardware automation towards autonomic functions. In line with this approach, the following scales of automation for traffic management centre operations are foreseen from the operators’ 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

Step A0 implies the existence of mainly hardware and possibly software modules that are capable of performing automated operations but are not designed to have any self-* characteristics.

Moving to step A1, the systems would have hardware modules that are designed with self-* properties, for example self-configuration or self-diagnostic. This is the first step that should start bringing benefits for the efficiency of traffic management centre operations.

Step A2 implies the implementation of software modules that have one or more autonomic properties. Traffic management centre systems can have this step without having A0 or A1, however the benefits would be higher if A1 is also present. With reference to the functional architecture introduced in the deliverable “Needs for autonomic functions in road operators' ITS”, software modules are considered to be those implementing the medium level functions.

Step A3 means autonomic properties for the high-level functions defined in the functional architecture. The step cannot be implemented without step A2.

Step A4 is when all subsystems have autonomic properties so the traffic management centre acts as an integrated autonomic system.

If analysing the automation from transport operator point of view, the following scales with the operator versus system roles and responsibilities could be listed (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 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 relied to make decisions in all situations. No operator involvement nor presence is needed

In addition, one could also see the automation scales from more general human operator point of view as done in the context of complex control and operating environments, such as controls rooms of nuclear power plants or large automated factories.

An autonomous system is the one, which can perform tasks (in this case traffic management tasks) in a dynamic environment without continuous human supervision, and possesses the ability to alter its behaviour based on its interactions with the surrounding environment (Geoffrey D. Ashton, U.S patent 9,360,320 B2, 2013).

An automated system denotes that the system may operate without direct human control often extended periods maintaining efficiency, productivity, high quality and reliability of object of activity. When an automated system can be regarded as autonomous in work environments, such as control rooms, depends on the defined scale of automation (SoA). There are many frameworks for describing the scale of automation, but in work environments e.g., in process control context Parasuraman & Sheridan (2000) ten-step ladder is often used (see Table 4.1) to make a distinction of how autonomous manner the system can work.

Table 4.1. Scales of automation in work environments

HIGH	10.	The computer decides everything, acts autonomously, ignoring the human
	9.	Inform the human only if it, the computer, decides to
	8.	Informs the human only if asked, or
	7.	executes automatically, then necessarily informs the human, and
	6.	Allows the human a restricted time to veto before automatic execution, or
	5.	Executes that suggestion if the human approves,
	4.	suggests one alternative
	3.	Narrows the selection down to a few, or
	2.	The computer offers a complete set of decision/action alternatives, or
LOW	1.	The computer offers no assistance human must take all decision and actions

The ten-step ladder has also been compared with the SAE (2016) automated driving levels by Rämä et al. (2017) (Table 4.2).

Table 4.2. The comparison of SAE (2016) automated driving levels with the 10-step ladder by context Parasuraman & Sheridan (2000)

SAE	Role of human as actor – responsible for detection, vehicle control		Role of human as decision maker - division of decision and operation responsibilities
5	Full automation full-time performance	10.	The computer decides everything, acts autonomously, ignoring the human
4	High automation	9.	Inform the human only if it, the computer, decides to
		8.	Informs the human only if asked, or
3	Conditional automation	7.	Executes automatically, then necessarily informs the human, and
2	Partial automation	6.	Allows the human a restricted time to veto before automatic execution, or
1	Driver Assistance	5.	Executes that suggestion if the human approves
		4.	Suggests one alternative
		3.	Narrows the selection down to a few, or
		2.	The computer offers a complete set of decision/action alternatives, or
0	No automation	1.	The computer offers no assistance; the human must take all decisions actions

It is clear that the level can be different for different functions in traffic management centres, especially during the transition period with stepwise increasing of automation.

4.2. Optimal automation for selected traffic management functions

This section describes the automation scales that are considered to bring the most benefits in the early implementation of automated traffic management functions mentioned in 3.2 in traffic management centres. These proposed scales should be the optimal choice in terms of cost/benefit ratio when starting the automation of the systems. However, the aim should be to further develop the management centres towards higher automation scales, ultimately trying to reach the highest scales. Nevertheless, every investment must be substantiated by a form of cost/benefit analysis as there might be automation scales for which the requirements are too high to be practicable and possible to implement.

The recommendations are based on the expertise of the authors and should not be considered as absolute implementation guidelines, but more as suggestions to achieve the desired goal of automating traffic management functions while taking into account budget and technical constraints.

Queue protection would be best implemented at step A2 looking from operators' perspective. This would mean, as is the case for current implementations, that there are software modules capable of autonomic functions without the whole system being designed as autonomic. From the transport operator perspective, it would be level 2 where the operator has a timeframe to interfere but otherwise the system decides the actions. Below these scales it is not considered that the Queue protection could bring any tangible benefits to the traffic management control operations.

To implement line control/traffic detour it would be best to start at step A2 from operators' perspective. From transport operator perspective, level 1 would be a good starting point. This would mean that the system only makes recommendations but the operators decides the actions to take. Further along the implementation, the line control/traffic detour function can be upgraded to level 2 where, as some current implementations, the system automatically decides on the actions and the operator intervenes only if considered necessary.

Stationary vehicle detection would be best implemented at step A2 looking from operators' perspective. This function is an ideal candidate for increased automation of traffic management centre operations. From the transport operator perspective, it should be implemented first at level 3 so in most situations the system decides the actions and the operator only needs to interfere when the system cannot take the decision because of some special circumstance that disturbs the automated process.

Automation of variable speed limits function could bring benefits starting from step A2. However, the implementation should move towards A3 as soon as possible in order to take advantage of the correlation between these function and other functionally related operations at the centre. Looking from the transport operator perspective, level 2 should be the starting point of automation so that the system automatically decides on the actions and the operator intervenes only if considered necessary.

Dynamic Lane Management is another good candidate for automation. It can start bringing benefits from step A2 where it would have autonomic properties even though the system as a whole is not designed to be autonomic. Level 2 from the transport operator perspective should be the start of automation for this function as it provides the opportunity to decrease the workload of the operators in most scenarios while they are still required to decide in certain situations when the system is not capable to select an action due to, for example, lack of accurate data or incomplete network coverage.

Temporary Hard Shoulder Running could be automated starting from step A2 and level 2 as even in the current implementations the system cannot be provided with enough information and it does not have the high scale of automation required to make the decisions without the interventions without the approval/intervention of the operator.

Automation of Ramp Management was shown to bring benefits in the current implementations where it is at step A2. From the transport operator perspective, it would be optimal to start at level 3 where the system takes action in most of the cases and the operator only intervenes in special situations

4.3. Optimal automation for selected traffic information functions

This section describes the automation scales that are considered to bring the most benefits in the early implementation of automated traffic information functions mentioned in 3.2 in traffic management centres. These proposed scales should be the optimal choice in terms of cost/benefit ratio when starting the automation of the systems. However, the aim should be to further develop the management centres towards higher automation scales, ultimately trying to reach the highest scales. Nevertheless, every investment must be substantiated by a form of cost/benefit analysis as there might be automation scales for which the requirements are too high to be practicable and possible to implement.

The recommendations are based on the expertise of the authors and should not be considered as absolute implementation guidelines but more as suggestions to achieve the desired goal of automating traffic information functions while taking into account budget and technical constraints.

Automation of information provision about unplanned events (incidents or obstacles) could start bringing benefits from step A2 and level 2 as it provides the opportunity to decrease the workload of the operators in most scenarios while they are still required to decide in certain situations when the system is not capable to select an action due to, for example, lack of accurate data.

Automated provision of information about planned events (roadworks) could start from step A2 and level 1. In the early stages of implementation, the benefits for the operators should already be relevant even if the system only provides options to be selected and validated.

Automated provision of weather information could start from step A2 and level 1. In the early stages of implementation, the system may not have enough data and network coverage to support levels 2 and beyond. However, based on current implementations, the benefits for the operators should already by relevant even if the system only provides options to be selected and validated.

5. Key performance indicators for measuring the effects of increased automation

The objective of defining these key performance indicators is to identify concrete references that can be used to assess the impact automation has on traffic management centre operations. Therefore, they should be useful for the road operator to measure if and how the automation changed their work.

In defining the KPIs, the SWOT analysis and implementation roadmap described in the deliverable "Needs for autonomic functions in road operators' ITS" were taken into account.

Two types of KPIs are proposed: deployment and operational. The **deployment KPIs** are focused on hardware components while the **operational KPIs** are almost entirely related to the software of the traffic management centre.

The following **deployment KPIs** are proposed:

- KPD1 – number of hardware components with automated alarms
- KPD2 – % of hardware systems with plug-and-play capability
- KPD3 – % of hardware modules capable of self-diagnostic and self-healing at least in 95% of cases without human intervention
- KPD4 – number of performed automated actions/unit of time
- KPD5 – % of traffic information messages updated automatically out of the total messages updated per day
- KPD6 – % of traffic information provided automatically per type of information
- KPD7 – % of automated operations with self-learning capability
- KPD8 – % of ratio of automated/manual road work/other maintenance operations planning per type of road

KPD1 to KPD3 are quite self-explanatory. KPD4 helps measure the level of automated actions that are performed by the system. It is defined per unit of time in order to provide meaningful and comparable results when assessing different systems.

KPD5 focuses on traffic information provision by the traffic management centre to the users. It is specifically targeted to measure the benefits of updating this information automatically without relying on the efforts of the human operator.

KPD6 is also linked with information provision by the traffic management centre and it gives an indication of implementing higher scales of automation with autonomic properties that allow the system to create and provide traffic information without the intervention of the operator.

KPD7 is defined to measure the implementation of self-learning capability which is a very important autonomic function for bringing the benefits of automation.

KPD8 is targeted specifically at automated road maintenance operations and is defined per type of road since automated maintenance can have visible benefits only on certain parts of the road network, especially those with high traffic volumes.

The following **operational KPIs** are proposed:

- KPO1 – % share of correct automated actions versus all proposed automated actions
- KPO2 – % reduction per year of operator man-hours for traffic management centre operations with reference to the introduction of the automation
- KPO3 – delays/decision times by automated system (could be compared by the ones of human operators)
- KPO4 – automatically detected incidents (compared with the ones by human operators)
- KPO5 – average latency (time needed) from incident detection to traffic information (compared to a human operator)
- KPO6 – average latency (time needed) from incident detection to traffic management operation (compared to a human operator)

KPO1 is defined to allow a simple assessing of the quality of the automation, seen from the perspective of the correctness of the automated actions of the system.

KPO2 is specifically targeted to measure one of the identified benefits of automation: less effort for the operators which should translate in a reduction of man-hours for the daily operations as compared to the levels prior to the introduction of the automation.

KPO3 can be measured against the performance of human operators but can also be relevant in terms of its trends as the system is developed towards increased automation levels.

KPO4, KPO5 and KPO6 focus on incident detection which is one of the crucial operations in a centre and one which current implementation proven could benefit from implementation of automation and autonomic functions.

6. Conclusions

The first objective of this report was to show lessons learned from implementing autonomic functions on roadside and traffic management centre systems. Chapter 2 presented an overview of implemented automated systems in existing traffic management centres and the results learned from each practice. All suggest two main conclusions: a) there are benefits from automation and b) further developments would be desired.

Chapter 3 discussed the expected benefits of automation and it presented a proposal for main traffic control/management and information functions. These are considered by the authors to be the most relevant functions that would bring identifiable benefits if automated. Different options for increasing efficiency of traffic management centre operations were also presented in Chapter 3.

Chapter 4 defined scales of automation from two different perspectives: the traffic management centre point of view and the transport operator point of view. They complement each other and were used to propose optimal automation paths and scenarios for the automation of the functions selected in Chapter 3. Automation levels widely used in control rooms (e.g. nuclear power plants) were also shortly introduced and compared to the SAE automated driving levels in Chapter 4.

Finally, chapter 5 proposed a number of key performance indicators that can be used to assess the benefits of increasing the automation of traffic management centre operations. Two types of KPIs are defined: deployment and operational. The eight deployment indicators are focused on hardware components while the six operational indicators are related to the software and processes of the traffic management centre.