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Task 4

Needs for autonomic functions in road operators' ITS. 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 is an updated and consolidated deliverable of the second and third deliverables of Task 4 – Autonomic road side ITS systems/Automation of road operator ITS.

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

The scope of this deliverable is to describe what autonomic functions could benefit to road operators in improving their operations, maintenance and provision of ITS services. The document starts by describing the existing autonomic functions and systems and proposes a new approach in terms of architecture and the implementation of the autonomic applications.

Task 4 is coordinated by ITS Romania (Mihai Niculescu) and DGT Spain (Ana Blanco) with participating partners from Finland, France, Germany, Italy, the Netherlands and the United Kingdom.

Acronyms

ADAS: Advanced Driver Assistance Systems

ANPR: Automatic Number Plate Recognition

CAD: Connected Automated Driving

CAV: Connected and Autonomous Vehicle

FRAME**:** the FRamework Architecture Made for Europe

GUI: Graphical User Interface

HGV: Heavy Goods Vehicle

HMI: Human Machine Interface

ITS: Intelligent Transport Systems

KPI: Key Performance Indicator

SAE: Society of Automotive Engineers

SWOT: Strengths, Weaknesses, Opportunities, Threats

TMC: Traffic Management Centre

TERN: TransEuropean Road Network

UAV: Unmanned Aerial Vehicle

VMS: Variable Message Sign

VMSL: Variable Mandatory Speed Limits

V2I: Vehicle to Infrastructure (Communication)

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1. Introduction

This chapter describes the scope and objectives of this 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 (TMCs) having as a main objective, efficiency and optimisation of ITS operations, maintenance and applications.

1.1. Scope and purpose

The scope of this report is to describe what autonomic functions could benefit road operators, in improving their operations, maintenance and provision of ITS services. The term autonomic is a biological metaphor adopted by IBM [1] 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. Autonomic systems are closely related to the broader field of Artificial Intelligence which covers software and hardware systems that exhibit human-like capabilities in terms of learning, situation awareness, interaction and problem solving.

The document introduces currently existing autonomic functions as well as systems, and then proposes a new approach in terms of architecture and implementation of the autonomic applications.

This document follows the work done in the previous reports “Autonomic functions implemented in existing ITS (status update 2019)” [2], “Needs for autonomic functions in road operators' ITS” [3] and “Good and bad practices from increasing the automation of road operators' ITS - Lessons learned” [4]. The reports explained autonomic behaviour and functions and also presented existing road operator systems with automated and autonomic-related functionality as well as lessons learned from implementing autonomic functions on roadside and TMC systems.

1.2. Methodology

The authors have identified the needs of road operators from previous studies and have aggregated and analysed all of them.

Based on the identified needs of road operators, the authors suggest a list of autonomic functions that can be installed. All these functions relate to the existing functions in TMC and other ITS applications. The needs are also used to define requirements for the installed autonomic functions.

Another important aspect presented in the document is the transition from installed functions to autonomic functions and the needs for intervention in terms of enhancing the efficiency and optimisation of the system.

The authors propose an ITS functional architecture for a Traffic Management Centre and suggest new elements and interventions in order to take steps to introduce autonomic behaviour to the system.

A SWOT analysis is also undertaken. It focuses on autonomic functions and systems which are able to be installed on the road to increase the safety and the efficiency of road operation and use. The SWOT analysis has two perspectives: internal analysis (SW) – directly connected with the autonomic functions and components of the system and external analysis (OT) – indirectly connected with the autonomic functions and the environment of the system.

1.3. Document structure

The document is divided in an introduction, four main chapters and conclusions.

The second chapter presents how major needs of road operators can be supported with autonomic functions of ITS systems. A selection of autonomic functions which authors consider most relevant is proposed and for each a mapping exercise towards road operator needs is performed.

Chapter three describes a detailed view on the implementation directions towards autonomic functions in TMC operations and services. The focus is mostly on TMC services selected in the previous report “Autonomic functions implemented in existing ITS (status update 2019)” [2].

Chapter four delivers a SWOT analysis of introduction automation in TMC. This chapter also proposes a roadmap up to 2030 for the implementation of automation in the current and future TMCs.

Finally, chapter five proposes a set of KPIs that can be used to measure the effects of introducing automation and autonomic functions. Also, targets for those KPIs are introduced. Both the KPIs and their targets are based on the analysis of the existing implementations and the expertise of the authors. They are not meant to impose any mandatory requirements on the implementers of TMCs, but rather provide an expert advice on assessing the benefits and return of investment from introducing automation into daily operations.

2. Needs of road operators and autonomic functions

2.1. Introduction

The purpose of this section is to present how major needs of road operators can be supported with autonomic functions of ITS systems.

For this, the deliverable “Autonomic functions implemented in existing ITS (status update 2019)” [2] of task 4 within EU EIP Activity 4.2 was taken as the main source of inspiration. Having reviewed this document in depth, it has been possible to identify the major shortcomings needed to be overcome, for optimum implementation and further development of autonomic functions.

In many European countries traffic centres are faced with multiple challenges in their daily operations. As the tasks increase and become more complex, there is a demand for more operators. However, in most cases there are budget constraints and it is not possible to hire additional human resource. In this situation, the increased automation of the operations with self-management and self-optimizing functions can lead to reduced work and a more efficient provision of services.

Another challenge in traffic centres is to react and adapt to malfunctions. In this case automated systems with self-diagnostic and self-healing properties can significantly contribute to faster reaction times and minimize the downtime of operations.

A third challenge relates to data collection. A basic operation for traffic centres is to collect traffic data and to provide traffic information to users. Often there are many sources of traffic data which need to be updated frequently. Also, the information provided to road users needs to be as accurate and as timely as possible. Introducing automated and autonomic functions for data collection/update and for traffic information provision reduces the effort required by human operators and increases the efficiency of the operations as a whole.

A fourth challenge relates to geographic expansion. Many times traffic centres need to expand their geographic coverage and/or extend their systems by adding more components: sensors, displays, consoles etc. New systems and components should be put into operation fast and integrated with existing systems. This can be easily done if components are automated with plug-and-play and a self-configuration functionality which also ensures better data integration between the systems.

A fifth challenge relates to infrastructure maintenance. Maintenance of the road infrastructure is the core responsibility of road operators. In order to be achieved efficiently, it is highly important to have a good planning of roadworks. Using automated tools for this is easier and more efficient than manual planning by the operators.

In view of the needs and challenges mentioned above, the next chapters in this section present the proposed autonomic functions and how they can be mapped to support answering each of the needs.

2.2. Selected autonomic functions

Based on the existing knowledge and our expertise, we believe that, in order to achieve the expected benefits for TMC operations, traffic centres should implement at least four high-level autonomic functions and two supporting functions. The high-level ones have influence at a more wider system scope while the supporting ones are lower in terms of system complexity and impact.

The proposed high-level functions are:

- self-management
    - management of the system itself
    - management of traffic
    - management of operational activities
- self-optimizing
    - 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 system(s)
    - customisation of the system

The following supporting autonomic functions should be implemented:

- self-learning
    - self-learning in the operation of the system
    - self-learning in the function of the system
    - self-learning in decision making processes and integration with other systems

  - self-learning in security
  - self-learning in autonomic functions
- self-diagnostic
  - support for self-healing
  - support for self-optimization

2.3. Mapping autonomic functions to needs

The following section describes in a schematic way the main needs identified for the implementation of autonomic functions by using real and specific examples for each case.

2.3.1. SELF-MANAGEMENT FUNCTION

It is necessary to define at least the most common range of scenarios to program specific algorithms for each event. Some examples could be:

- Accident detection → automatic signalling → alternative routes
- Road congestion → automatic signalling → travel times
- Adverse weather conditions → automatic signalling → changes in traffic conditions, speed limits, etc.

Once the main causation is clear, it would be interesting to go further implementing new and non-recurrent scenarios (for example reaction in case of unforeseen infrastructure damage).

2.3.2. SELF-OPTIMIZING FUNCTION

The establishment of quantitative criteria is highly important. Depending on the situation, the best solution can be achieved by applying different criteria for each action. In this sense, this function is always associated with numerical valuation for decision making.

- Road blockages: strikes, demonstrations, specific roadworks → Rerouting → Best solution: minor distance + less congested option of allowed routes
- Ramp metering → Comparing the average time needed for the incorporation, the distance between vehicles and the speed of the main stream, it is possible to adjust and optimize the entrance of the vehicles to the motorway depending on the circumstances.
- Reversible lanes activation: specific traffic intensity analysis → Balance between directions and definition of a determinate value combination for the actuation

- Opening/closure bus hard shoulder running for specific instances → High congestion → Which value is considered as high congestion?

2.3.3. SELF-HEALING FUNCTION

For the implementation of this function, it would be necessary to define which components can fail for each system without altering the normal operation, as well as alternative mechanisms to the damaged ones to guarantee the service provision

- Communication networks → In case of failure in the communication system usually used by the device, to consider the possibility of using alternative connections in order not to lose the transmission of data (optical fibre, private GSM, cellular networks, wireless networks, vehicle communications, etc.)

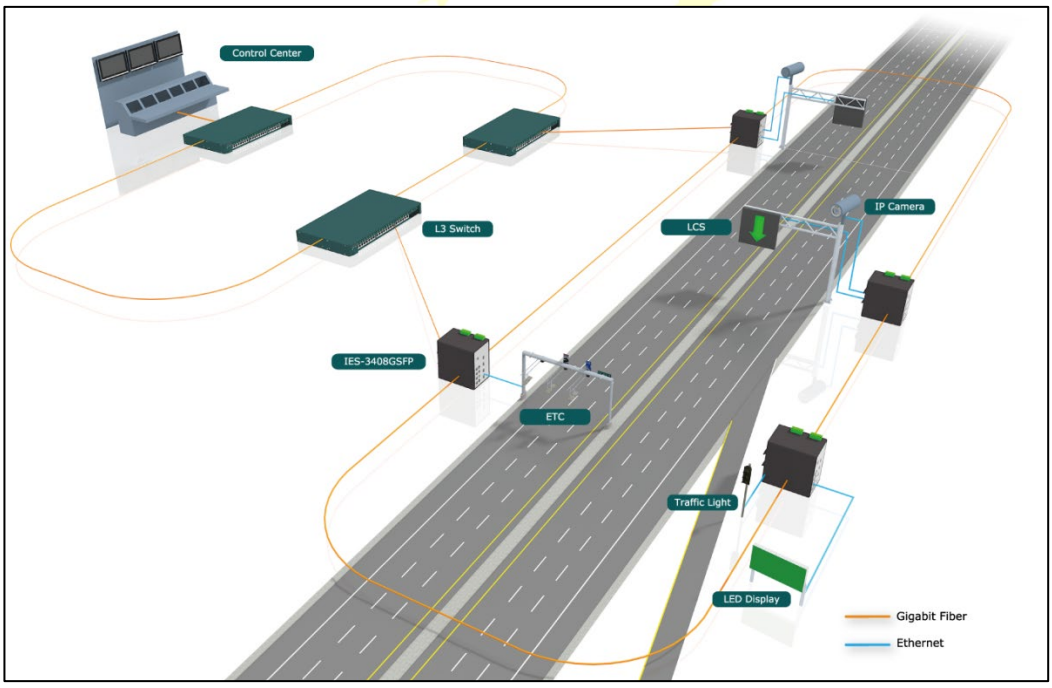

Figure 2.1 Example of alternative communication systems in case of failure (source: Lantech)

- Energy blackout → It would be advisable to take into account the inclusion of alternative equipment that restore power automatically when there is trouble or a fault in energy transmission.

This function is closely linked to self-diagnostic function, which consists in the detection of errors and failed components.

In conclusion, for the implementation of the self-healing function, it is necessary to guarantee the following issues: good diagnosis and real alternative measures.

2.3.4. SELF-CONFIGURATION FUNCTION

In order to attain the aim of the function, it would be necessary to design or reprogram existing systems for adapting their operation to the new guidelines or needs automatically, without requiring remote configurations or fieldwork.

This function is highly advantageous from the point of view of time management and resource management, since the inclusion of new equipment or the need to make updates on them would be done directly without the need to invest personal or material resources to do it.

2.3.5. SELF-LEARNING FUNCTION

The use of machine learning applications including those using neural networks for data processing is the key for this function. Analysing the amount of data obtained it is possible to assess the level of improvement reached due to the implementation of self-management and self-optimizing functions.

- Ramp metering → The data acquired from ramp metering can be used for training and based on this, a more optimised algorithm can be realised.
- Opening/closure of special lanes → Relying upon the contour conditions of the analysed scenario (number of lanes, traffic intensity of each lane, hard shoulder width, length of the congested section, etc.) the opening or closure of special lanes may apply in different moments. Analysing and comparing times and values of congestion and the moment when the measure is applied, the system should be able to decide the appropriate instant to implement the automatism for each case.

The capability of mechanisms to manage data and the ability to make decisions based on other experiences is a key aspect in development and implementation of autonomous functions in ITS devices.

2.3.6. SELF-DIAGNOSTIC FUNCTION

The identification of all the possible errors that may occur in each device, and how they convey what is failing, is essential in order to take action on them. The diagnosis, as described in the above section, is crucial for being able to address the problems.

Different kind of errors shall be considered:

- Inconsistent data → Need to analyse the status of the sensors. Which one is failing and why?
- Communication break → Need to explore where the interruption is.

Also, for this function, it would be helpful to identify and consider early warnings like:

- Own alarms for each device: low battery, open door, voltage fault, configuration, etc.

Depending on the type of error, the way to transfer the information and the way to interpret the stored data may be different. Every sensor and device should send keep alive messages in defined intervals. With these it's possible to see if the devices are still "alive"/working.

2.4. 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, as does the time to develop the system. Fortunately, the increased benefits pay off. 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; this 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 additional resource. 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 downtime 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.

2.5. Scenarios for increasing efficiency of traffic management centre operations based on automated and autonomic solutions

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.

- **Intermediate 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.

2.6. General overview of automation needs

In view of the above, it can be concluded that specific operational needs for traffic management can be enhanced with the support of ITS systems autonomic functions.

In general, each function responds to specific needs but, at the same time, all functions are closely interrelated.

Finally, for the purpose of providing a global snapshot of the results, the following figure seeks to summarize the main concepts reflected throughout this section.

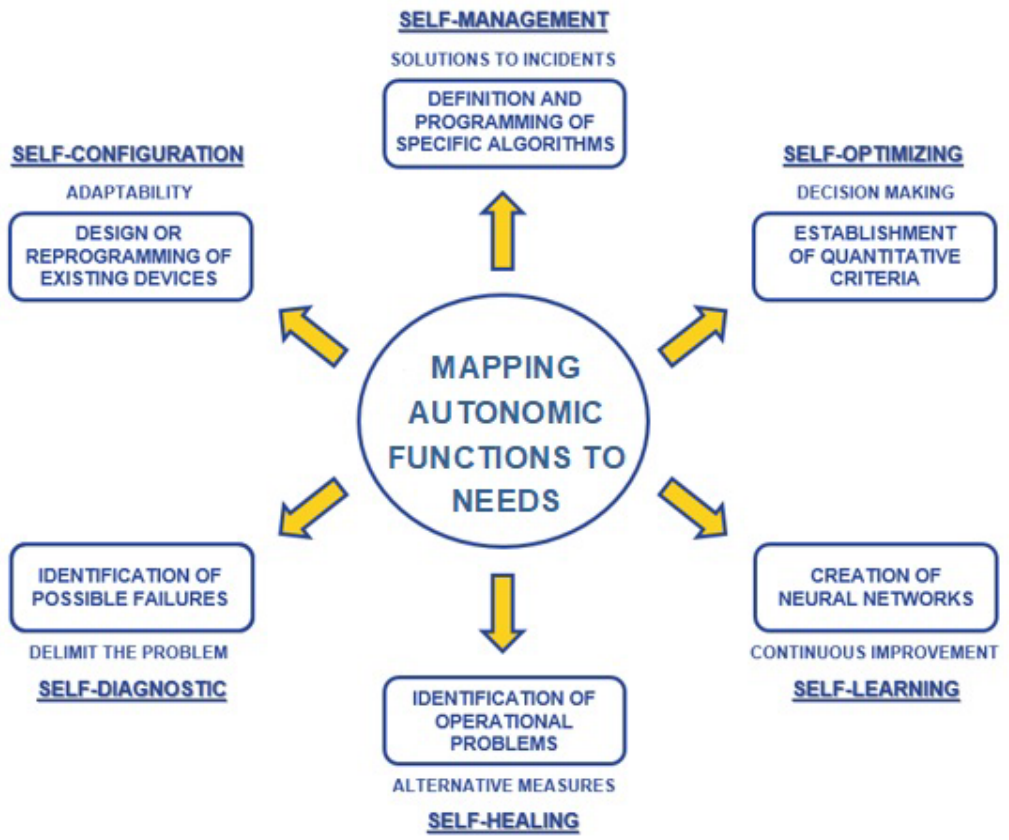

Figure 2.2 Mapping autonomic functions to needs

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3. Implementation of autonomic functions

The main objective of this chapter is to identify the implementations of the autonomic behaviour in existing functions of ITS and the trend in the deployment of autonomic functions in future implementations.

The evolution of autonomic functions from the beginning, some steps towards automated processing, through to the existing level of autonomic systems is considered.

3.1. Evolution of ITS functions towards autonomic functions

The evolution towards smarter, future roads means helping the creation of a technology-friendly ecosystem for both infrastructures and vehicles.

This will lead to the creation of innovative services for users: both for the transport industry and for individuals. In turn this will likely be leading to more efficient use of vehicles, minimisation of congestion and optimisation of infrastructure.

Additionally, the availability of a multitude of on-board sensors in vehicles has created new challenges and possibilities.

Integrating this data with other measurements, i.e. combining it with remote sensing techniques and modelling approaches, can provide improved products and services to road users, service providers, and traffic management agencies, supporting decision making.

All this needs to be done ensuring suitable levels of safety of the structures and traffic, through continuous knowledge of their characteristics.

Key roads of the TERN already have a technological backbone that makes the evolution towards some of the services feasible; making the evolution possible for some services in a reasonable period of time. To achieve the benefits listed in section 2.4 there needs to be a fair evolution of the road system that should be configured as a set of systems and services for mobility, managed and offered by different operators, in an integrated environment, made possible by an open and distributed architecture. Moving in this direction, smarter, future roads will benefit from the continuous technological evolution of vehicles that shall be increasingly equipped with ADAS, self-driving functionality and permanent connectivity. This will additionally offer the road network with new opportunities for technical evolution and new business.

While increasing the level of vehicle automation, the driver shall have less manual control and focus more on supervision. This way drivers, when higher levels of automation are reached, can enjoy quite a different travelling experience: the interaction between the vehicle and the road and the other vehicles can be more and more left entirely to the vehicle or be distributed between the vehicle and the infrastructure, in the case of roads in the future.

Measurements and monitoring of the road and features allow a systematic identification and representation of several categories of data. Into this frame, and following the criteria adopted by Delegated Regulation 962/2015 for the provision of EU-wide real-time traffic information services, the following categories can be considered:

- Static characteristics of traffic on road and network infrastructures (e.g. geometry, width of lanes, road signs, speed limits, toll infrastructures, etc.);
- Dynamic characteristics of traffic on road and network infrastructures. Examples within this category are: roadworks, temporary criteria of operation (e.g. reversible lanes or hard-shoulder running, etc.), road conditions, recommended speed or variable speed limits if different from the static, etc.;
- Traffic and travel data (e.g. traffic volumes / flows, predictive queue warning, average or local speed, travel times, etc.).
- Both traditional and innovative ITS services can be a source for collecting traffic and travel data. By way of simplification one can mention:
    - Infrastructure based equipment (roadside, over ground, drowned in floors, drowned or applied on the structures themselves, etc.);
    - probe data or crowdsourcing, data voluntarily provided by travellers, via personal and onboard devices, through the dedicated platform;
    - other information to be achieved directly from vehicles but using the appropriate V2I communication platform and/or conventional communication methods.

ITS data processing is needed for the purpose of:

- obtaining indirect or comprehensive data analyses
- integrating direct monitoring data with additional complementary sources or correlate data from different monitoring or data sources
- realising spatial extensions or time projections

Road operators need to compute the information and other data outputs of the monitoring process, to achieve detailed estimates and forecasts. The operator of main routes (i.e. the TERN network) will normally have a distributed organisation with staff members able to cater for collecting and validating data coming from possible crisis area, then are able to transform the data in short and medium term forecasts.

Road operators and road authorities validate data collected and assess the quality. Both road operator and third parties can enrich the contents with data and processing from additional complementary sources. This results in a distributed system of content-providers.

3.1.1. DATA COLLECTION FOR INCREASED AUTOMATION

In recent years new and advanced monitoring technologies have become available, but with respect to automation the most relevant advances been in performance and capability; improving installation, configuration and data analytics; thus increasing overall usefulness of the products. This has led to more self-configuration, self-learning, and self-diagnostics functionalities.

The following automated features are commonly available:

- Auto configuration
- Diagnostic capabilities
- Fault monitoring and alerting
- More pre-installed logic
- Maintenance alerts

3.1.1.1. SENSOR DATA

The following section examines common road operator data collection and describes aspects that can include automation.

Traffic data: for the purpose of this report this includes spot speed, volume, occupancy, classification.

Fixed infrastructure technologies for collecting traffic data include traditional inductive loops and non-intrusive traffic detectors, such as microwave and radar units. Device software can automatically configure devices (with units also being reconfigured remotely if required); logic features include automatic lane direction configuration and wrong way driver detection capabilities.

Environmental data: includes weather data and air quality. Road Weather Information Systems can be made up of networks of automated weather stations collecting atmospheric and weather data. Additionally, requirements to use remote-sensing data and integrate those with surface weather measurements have increased, along with the technical capabilities.

These systems can automatically undertake sensor calibration, maintenance activities, and configurations. Combining raw data from road sensors and atmospheric observations allows the systems to provide more accurate surface state analysis. Automatic alarms and alerts can be generated, and decision support software can recommend weather treatment / pre-treatment plans.

Imaging techniques: can provide basic traffic data as described above, plus more advanced data. Data sources include cameras, radar, and LIDAR units. By processing and analysing images, additional capabilities including calculation of Level of Service, the ability to identify and track different objects (vehicles, people, animals, debris), and analysis of junction movements can be achieved.

Imaging algorithms can also “learn” to identify car features like type, make, model and colour in a more systematic way. Image processing systems can automatically take control of cameras and track target people or vehicles with automatic handover to the camera with the best view.

Imaging techniques are also used in asset management / pavement assessment, with self-learning and self-optimization features to capture and classify assets, and maintenance requirements.

Travel time data: can be obtained from fixed infrastructure, probe vehicle GPS techniques, or CAVs. Fixed infrastructure includes Bluetooth, WiFi, ANPR and Automated Vehicle Identification technologies, these calculate travel times between monitoring devices providing link travel times. Many map service providers employ their personalised GPS data for travel time forecast services and commercial products, covering road sections where their customers are present.

Incident data: incident detection involves both the collection and analysis of traffic data, with faster detection of traffic incidents being of extreme importance for maintaining a higher level of service for road users. Currently most spot sensor based automatic detection systems cannot detect the incident until the shock wave reaches the flow of traffic to the nearest sensor, then the system will begin to measure the character of the traffic. With advanced algorithms and AI; and by combining data from several sources, UAV video detection, vehicle-to-vehicle (V2V), or vehicle-to-infrastructure (V2I), incidents can be detected more quickly, classified more accurately, with lower false alarm rates. The field of incident prediction is also advancing, with shockwave estimation to predict incidents and prediction of secondary incidents.

3.1.1.2. DATA REPOSITORY

The data from field devices must be organized and recorded in appropriate databases.

Search and access to data need to be possible both by the owner of the data and – if pertinent - by accredited (non-final) users.

An open-data approach can apply to pertinent data set.

Databases can be articulated according to three major repositories:

- Disaggregated (raw) data level; it reports the data as collected and transmitted by local devices. The data is entered into the database after being extracted from the packets used for the transmission, with no elaboration.
- A second repository refers to so-called current data; these are the useful data, extracted from raw by ETL tools (Extract, Transform, Load). Data information is maintained at a high level of detail. It is reasonable to assume that most real-time information services can be based on information contained in current data.
- Historical data repository; it refers to a further process aimed at obtaining descriptive statistical values of the traffic phenomenon. It is reasonable to think

that historical data is used mainly in off-line mode and for scheduling and maintenance applications. Historic data are retained.

3.1.1.3. DATA MANAGEMENT

Data management includes numerous repetitive tasks in aggregation and curation that can benefit from automation. Applying automation to large data repositories could improve the efficiency in tasks such as:

- Data input,
- Migration of data between dissimilar data stores,
- Data combination, such as aggregation to provide richer data sources for advanced processing algorithms
- User access to large data sets with the help of custom configured chat bots [5]
- Screening for irregularities and improving data quality through repetitive tasks
- Enabling input and verification of manual processes
- Data deduplication and data extraction applied to new data sources
- Creation or updating of metadata

3.1.2. TRAFFIC MANAGEMENT AND AUTOMATION

A transition is expected from traditional ITS to the future configuration when ground ITS application shall be demanded to cooperate with automated vehicles (with levels SAE 3 and 4 applications on board). During this transition phase, a long period of mixed traffic on the network shall be experienced. Automated and human driven vehicles shall share the same roads and the same road network.

3.1.2.1. PERFORMANCE ANALYSIS

Performance analysis provides the opportunity to continuously assess the performance of the various road sections. It is necessary to provide features that feed a historical performance data base, including road safety data. Among the functions for analysing the performance of significant sections of the road network are:

- analysis of current performance by comparing current data and target data (traffic efficiency);
- safety data analysis for comparing different network sections;
- infrastructure data analysis (e.g. frequency and duration of roadworks) with comparisons between homologous traits;
- maintaining living files for security, efficiency and resilience of the infrastructure.

3.1.2.2. *Traffic Management Plans (TMPs)*

A TMP is the pre-defined allocation of a set of measures to a specific situation in order to control and guide traffic flows as well as to inform road-users in real-time and provide a consistent and timely service to the road user.

Using archived data makes it possible to produce traffic forecasts, identify possible traffic management strategies, simulate the impacts, and define coordinated intervention scenarios. A concerted intervention scenario is characterised by the:

1. concerned network
2. location
3. list of events that motivate the scenario
4. type of TMP
5. localisation factors
6. severity
7. list of actions contained in the scenario (e.g. closures, diversions, speed controls, information)

For each scenario applied, the start and end time and all scenario data will be stored. Possible functions are:

- Data analysis to estimate O/D matrices and route choices for different types of vehicles, hours, and daytime types
- Short, medium and long term traffic forecasts (from one hour to several months), under normal conditions
- Simulation of traffic with different scenarios and in the presence of several abnormal events
- Defining coordinated management scenarios (with simulation of effects)
- Scenario store management
- Decision on the activation of scenarios in case of anomalous events
- Scenario management enabled

A set of selected scenarios could be made public (in the appropriate forms) for knowledge by all decision-makers in the affected regions and information service providers.

3.1.2.3. *Operational Traffic Management*

During exceptional or unexpected conditions operators can struggle to find a strategy intervention tailored to address the current situation. Creating such strategies can be a manual task that may take several days or weeks, and it is therefore infeasible to manually create one in real-time. Semantic technologies enable the enrichment of data sources, linking them with additional information, thus providing context and aiding data cleansing.

In the future, systems could work by sourcing and semantically enriching traffic data, and using derived knowledge as input to an automated planning component, creating strategies in real time.

For this purpose, the analysis and simulation functions already listed in the prediction area and, where applicable, the deployed scenarios can be used. Possible actions include:

- rerouting, in case of serious obstructions;
- interventions on average speeds, to avoid or solve congestion (speed control);
- suggestion of trajectories and lanes (lane control);
- queue protection,
- dynamic access management (ramp metering);
- traffic light management.

Possible functions are:

- analysis of alarms received on various events;
- verification of the scenario archive and, where existing and corresponding, decision on their application;
- implementation of automatic control methods (speed, lane, ramps)
- performance indices and sensor data triggering decision making tools.

3.1.3. INFORMATION DISSEMINATION

Traveller information systems can be automated data fusion and dissemination systems that can provide a consistent, enhanced overall view of the transportation network. This can include road traffic, public transport, crowd-sourced data, weather, roadworks, and event information; prioritised, analysed, and delivered in a useful way to road users via various methods. Using historic data, traffic condition / travel time forecasts can be made for typical days, holidays or events.

Connected vehicles will receive information on road conditions, hazards, the presence of neighbouring vehicles (including non-line of sight in obstructed / reduced visibility conditions). A CAV will potentially be able to combine the information received from its sensors (e.g. camera, radar, LiDAR, ultrasound) and the connectivity systems to improve overall vehicle performance and make more informed and intelligent decisions.

On-road signage for human driver shall coexist with services for automated vehicles. The traditional signs and signals with indications and obligations, complemented by ITS systems, which is currently mainly through VMS. The automated reading of roadside displays and signage could complement in the transition phase.

As noted previously, the pace and scale of evolution of ITS functions will depend on the level of automation adopted and integration of automated systems.

3.2. Functional architecture of an autonomic TMC

The proposed functional architecture is focused on autonomic functions of the ITS and has as main reference FRAME Architecture [6] (the security components are also defined to be part of the new approach).

The proposed architecture consists of high level functions which are further broken down into medium level functions.

The high level functions are numbered using the notation HL*x*, where *x* is a digit starting at 1. The medium level functions are numbered using the notation ML*x.y*, where *x* represents the digit of the parent high level function and *y* is a digit starting at 1 for each group of medium level functions.

The functional architecture at high level functions is presented in the figure below.

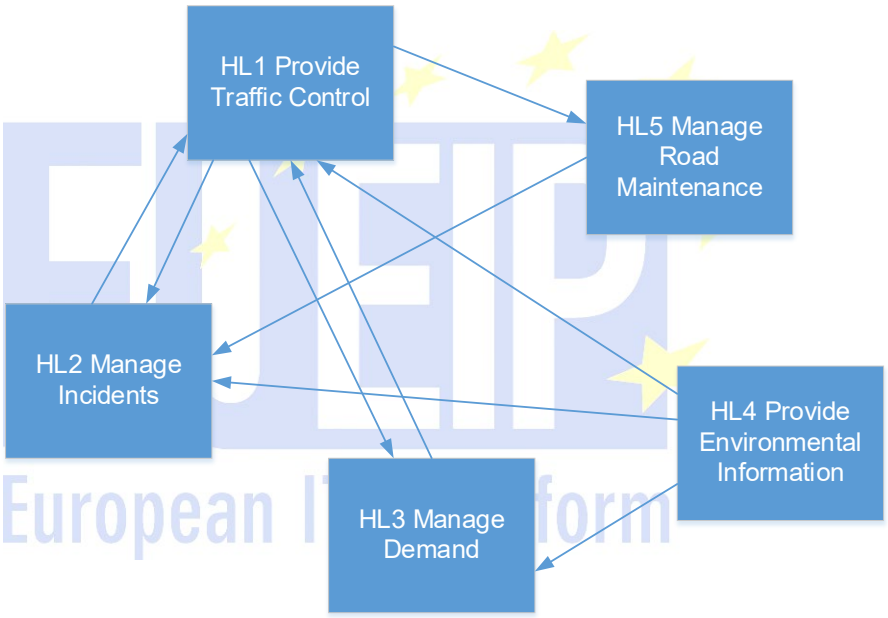

Figure 3.1 Functional architecture – high level functions of Traffic Management

The functional architecture of TMC (or, in this case, management of traffic, in general) is the main component of the ITS architecture which is dealing with the definition of the functions. The main challenge in terms of autonomic behaviour is to find the candidate functions which can be developed in an autonomic way. Another important component of the functional architecture is the data flow. This flow of data could be designed as an autonomic exchange of data between different functions.

The table below shows the relation between the components of the functional architecture and the operational functions of the TMC selected as most relevant for automation in [2].

Table 3.1 Functional architecture and operational functions of the TMC

Components of the functional architecture / Operational functions of the TMC	Provide Traffic Control	Manage Incidents	Manage Demand	Provide Environmental Information	Manage Road Maintenance
Information on unplanned events (incident/obstacles information)	x	x			
Information on planned events (roadworks information)					x
Traffic time information			x		
Queue protection		x			
Line control/traffic detour			x		
Stationary vehicle detection		x			
Variable speed limits	x				
Dynamic Lane Management			x		
Temporary Hard Shoulder Running			x		
Ramp Management			x		
Weather (actual and predictions) information				x	
Design of traffic management plans			x		
Calibration of traffic management equipment/systems					x
Cross-border traffic management	x		x		
Wrong way driver information		x			

The functional architecture is defined based on two autonomic components: autonomic functions and autonomic data flows (flows and functions which are dealing with the exchange of data among the ITS functions).

Only the following more complex high level functions will be broken down into medium level functions:

- HL1 Provide Traffic Control
- HL2 Manage Incidents
- HL3 Manage Demand
- HL5 Manage Road Maintenance

Function “HL4 Provide Environmental Information” is seen as a less complex function which mostly feeds information to other functions. Nonetheless, increased automation can also be applied to this function in terms of highly accurate and highly automated weather information and predictions.

The proposed architecture for the function “HL1 Provide Traffic Control” is presented in Figure 3.2 below.

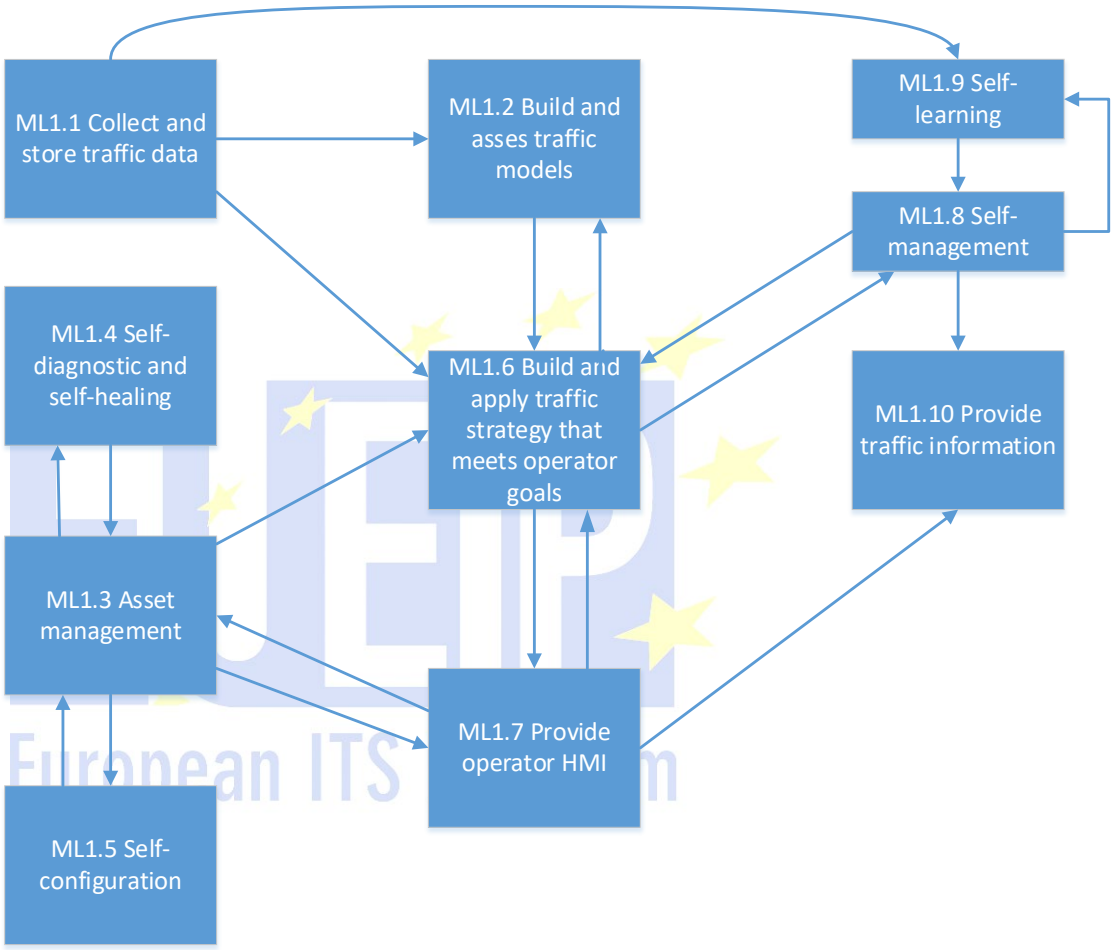

Figure 3.2 Traffic Control - Medium Level Functions

The main component for traffic control is to collect and store (for historic analysis) traffic data. This addresses all methods (from loop detectors to floating car data) and all categories: flow, travel times, average speeds etc. The function also feeds other high-level functions connected to “Provide Traffic Control” function in the high-level architecture.

The proposed architecture includes an asset management function which is connected to self-diagnostic, self-healing and self-configuration functionality. Here asset management is intended to cover all hardware components of the TMC. The self-configuration

functionality has to cover component malfunction, geographic or hardware reconfiguration as well as changes in the high-level architecture for highly automated TMCs.

The core of the traffic control is to build and apply traffic strategies that meet the operator goals. This can be done fully automated or semi-automated, relying on operator validation. In either case, it should be an automated feedback-loop process that builds on self-management and self-learning from constantly assessing the impact of the chosen strategies to the traffic situation. Also input from asset management has to be taken into account in order to adapt to component failures and system reconfigurations.

The traffic control will be put into action through traffic control measures (HGV overtaking ban, dynamic speed limits, rerouting advice etc.) and will provide traffic information (travel times, congestion etc.) through various means from VMSs to web portals and in-car information.

The “Provide operator HMI” and “Provide traffic information” functions are present here and will be mentioned in other high level functions. However, they are seen as a common functionality shared by all high level functions.

The proposed architecture for the function “HL2 Manage Incidents” is presented in Figure 3.3 below.

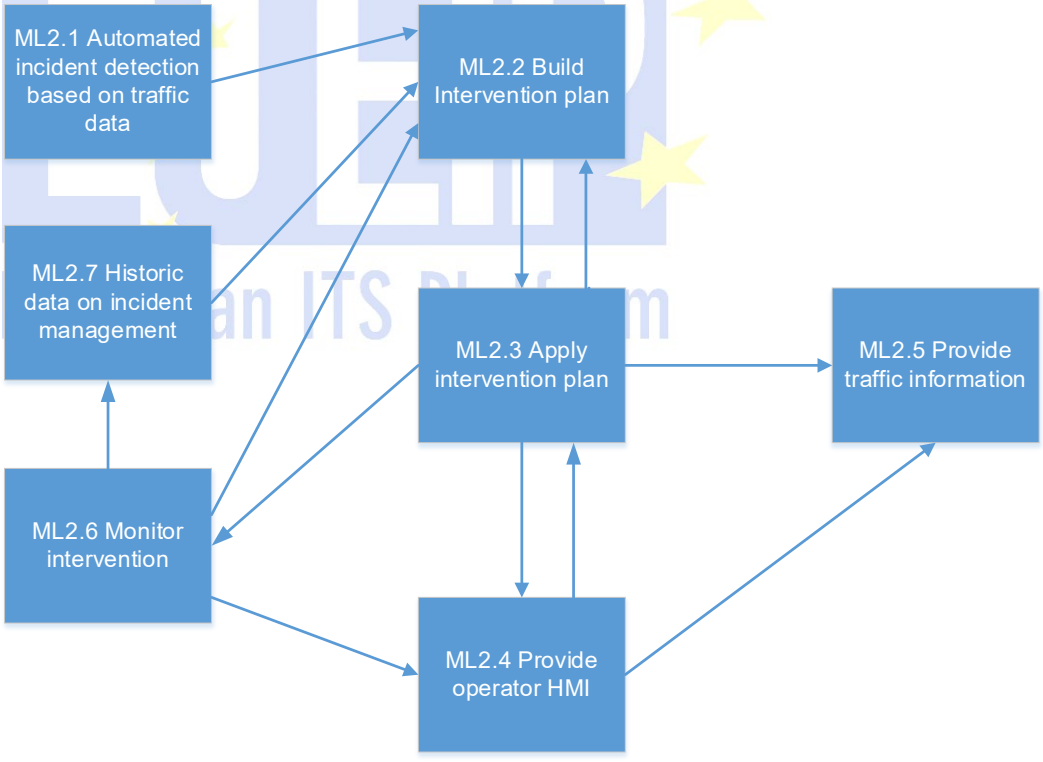

Figure 3.3 Architecture of Manage Incidents function

The autonomic behaviour of “Manage Incidents” function builds on three elements:

- automated incident detection
- automated build of incident intervention plans based on pre-defined measures and self-learning from historic data of previous interventions. A continuous feedback-loop is used to monitor the effect of the interventions in order to adapt them so they reach the goals set by the operator
- automated implementation of the intervention plan (lane closure, diversions, speed limits etc.).

The architecture foresees the option for the operator to intervene in order to control/influence every step from incident detection to putting into operation of the intervention plan.

The proposed architecture for the function “HL3 Manage Demand” is presented in Figure 3.4 below.

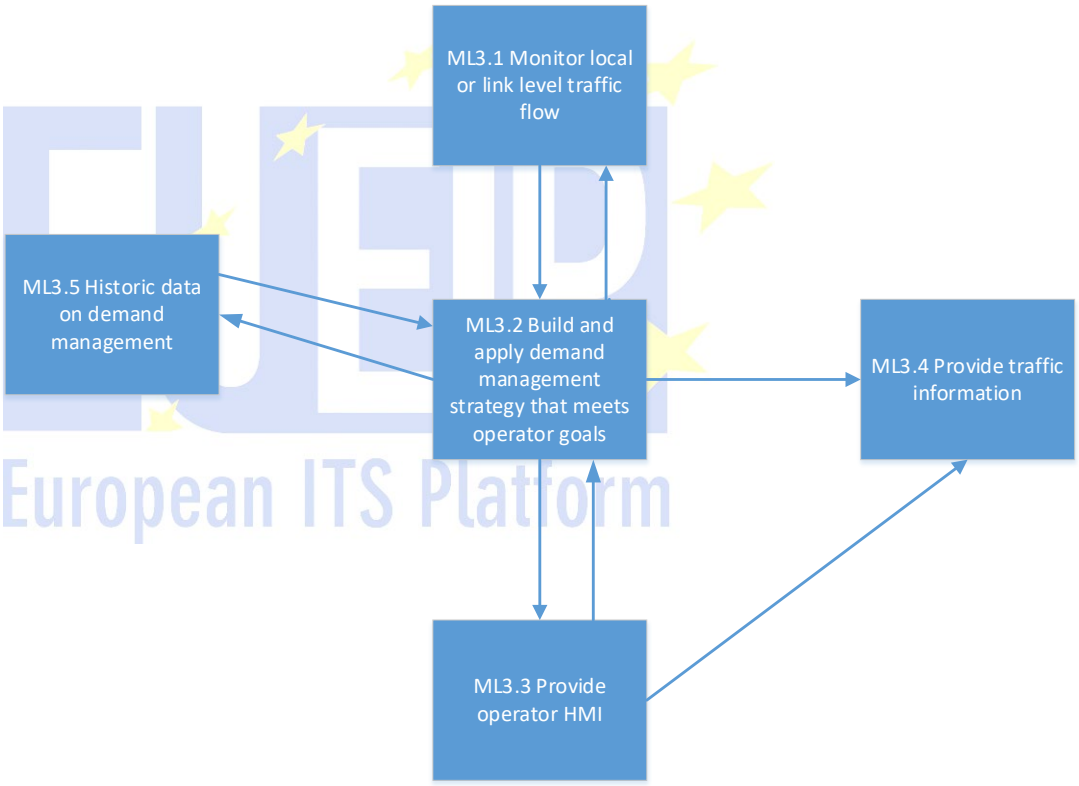

Figure 3.4 Architecture of Manage Demand function

Demand management can be performed at “link level” (i.e. motorway section) or “local level” (i.e. ramp metering, tunnel entrance or bridge crossing). The function must be fed with traffic flow information from the “Provide Traffic Control” function which will be used to compare with the intended results of the applied strategy.

The autonomic behaviour of “Demand Management” function builds on two elements:

- automated implementation of the management strategy (hard shoulder running, lane closures, ramp metering, dynamic speed limits)
- self-learning from the results of the previous demand management interventions.

The proposed architecture for the function “HL5 Manage Road Maintenance” is presented in Figure 3.5 below.

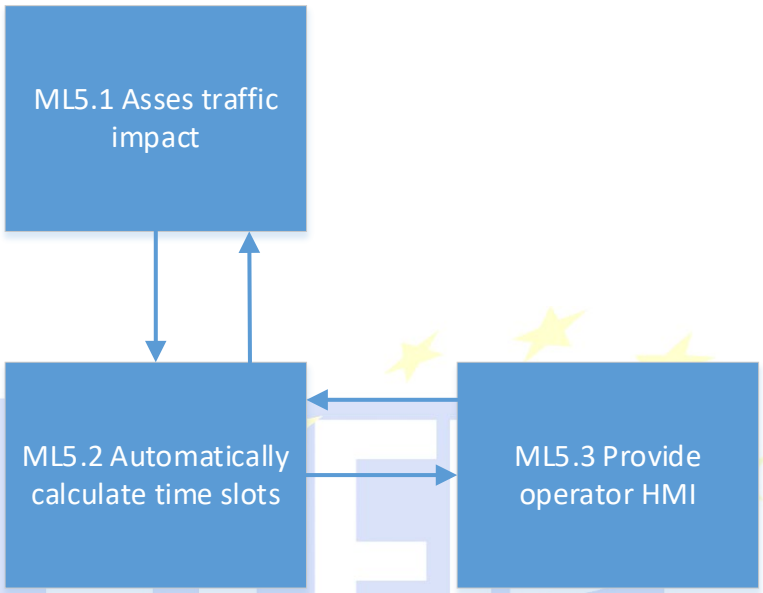

Figure 3.5 Architecture of Manage Road Maintenance function

The function must be fed with traffic status information from the “Provide Traffic Control” function which will be used to assess the impact of the calculated time slots for work management operations.

From a functional perspective, the level of automation in a TMC starts from the basic level of components (self-healing and self-configuration). This can reach highly automated/autonomic medium level functions and further acquire full autonomic properties at system level among the high-level functions.

4. SWOT analysis on the implementation

4.1. SWOT analysis

The SWOT analysis is an acronym for Strengths, Weaknesses, Opportunities, and Threats. The analysis is a structured planning method that evaluates those four elements of e.g. organizations, projects or business ventures. In this chapter, a SWOT analysis for an increased automation in traffic management centres is performed.

4.1.1. STRENGTHS

For analysing strengths of an increased automation in traffic management centres, the following general questions are discussed:

- What advantages does automation respectively increased connectivity have?
- In which aspects is automation better than manual functions?
- What is unique in automation compared to manual operations?

A non-exhaustive selection of strengths is shown in Figure 4.1.

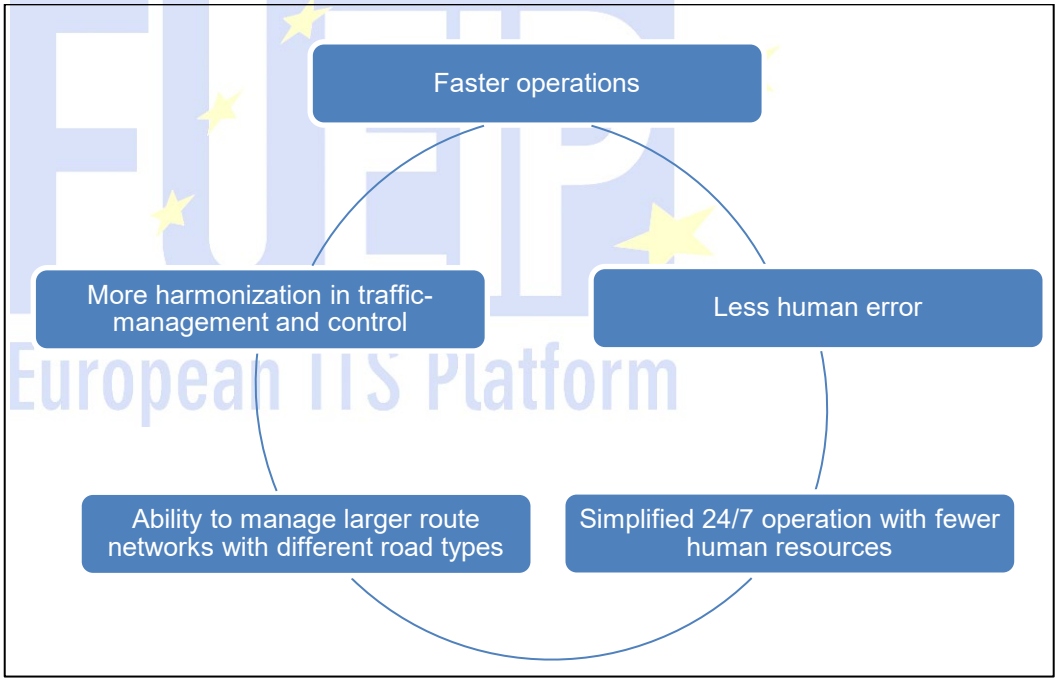

Figure 4.1 Strengths of automation in TMCs

As shown in the figure, there are different strengths of automation in traffic management centres. It enables to react more directly to changing traffic conditions and to offer a more targeted service. Furthermore, automated traffic management simplifies 24/7 operation because fewer human resources are needed.

Additionally, operating errors due to human errors can be decreased and automated traffic management can cover a larger road network with different road types. Another strength of emerging automation in traffic management centres is that traffic control is becoming increasingly harmonised and can therefore better meet the challenges, especially in metropolitan areas with a high volume of traffic.

4.1.2. WEAKNESSES

To analyse the weaknesses of an increased automation in traffic management centres the following general questions are discussed:

- What risks should be taken into account and what strategies should be chosen?
- What should be avoided when increasing automation in traffic management centres?

A non-exhaustive selection of weaknesses is shown in Figure 4.2.

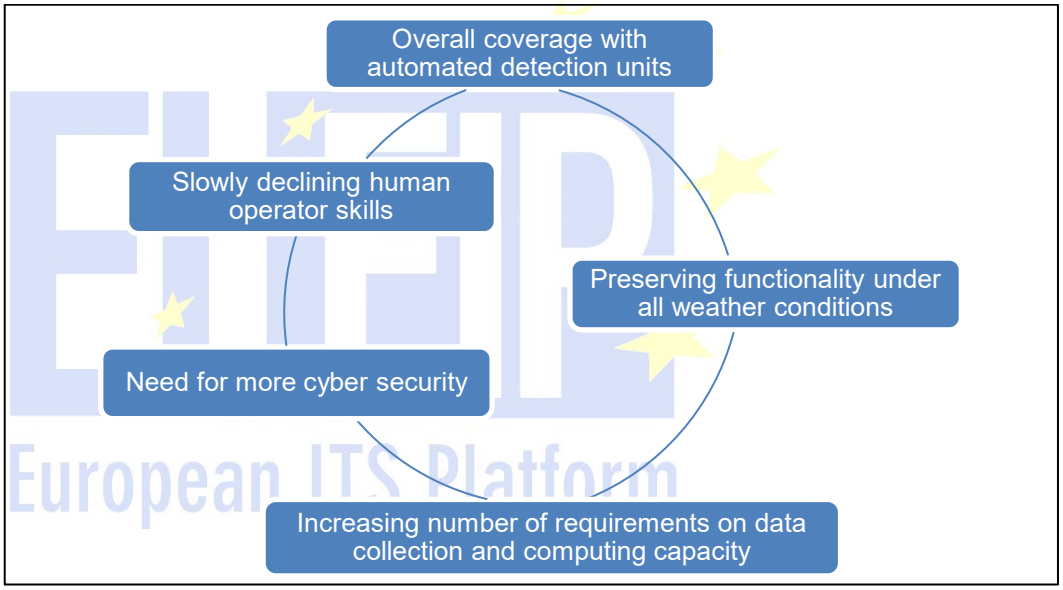

Figure 4.2 Weaknesses of automation in TMCs

The more automation in TMCs is introduced, the greater are the demands on a comprehensive deployment of detection units. Equipping the road infrastructure with detection units is associated with high financial and material expenditure.

Furthermore, possible technical limits of the detection units, for example in consequence of extreme weather, must be eliminated in order to guarantee their functionality under all conditions and thus provide the basis for automated traffic management.

Due to the large amount of data collected from road traffic, it is necessary to provide high data transfer speed and computing capacities to meet the demand for real-time traffic management. This is associated with an intensive expansion of communication infrastructure. The resulting data centres require a lot of space, memory capacity and need

to be maintained. The increasing amount of traffic information leads to an increased need of protection of this information. An essential point is cyber security, not only for the data itself, but also for the interfaces.

Increased automation of operations could also lead to a slow decline of human operator skills because they are no longer required to decide themselves what traffic management and control measures should be applied.

4.1.3. OPPORTUNITIES

For analysing opportunities of an increased automation in traffic management centres, the following general question is discussed:

- What kind of positive impacts does increased automation have on road transport in general?

A non-exhaustive selection of opportunities is shown in Figure 4.3.

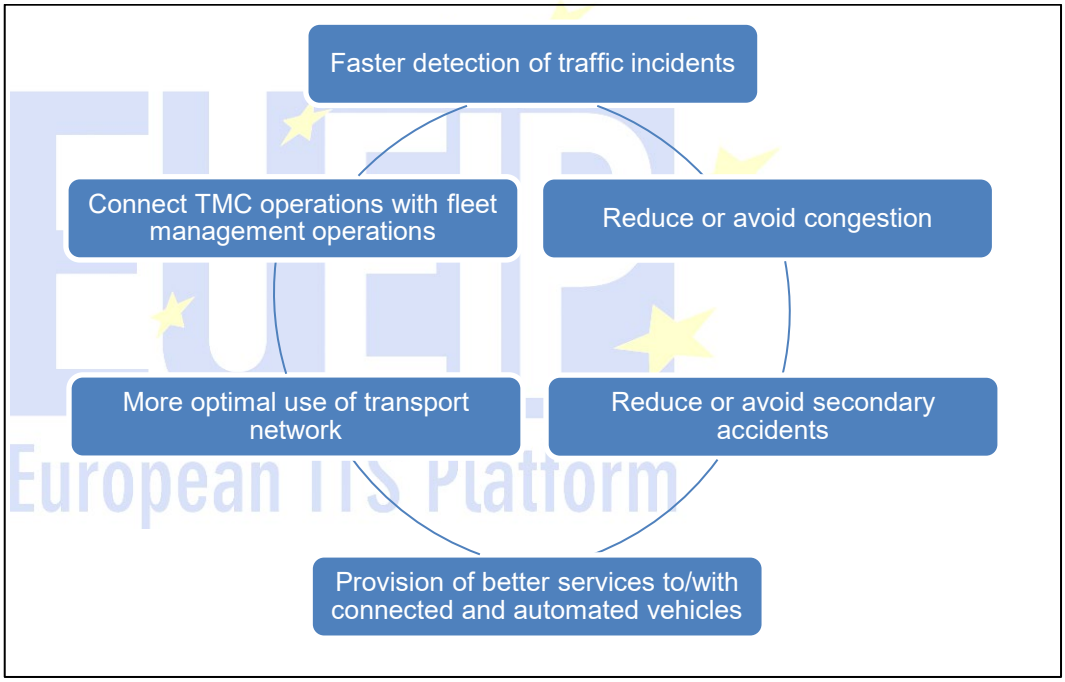

Figure 4.3 Opportunities for automation in TMCs

A great opportunity for automation in TMCs is attributed to faster detection of incidents especially with an increased number of automated/networked vehicles collecting data on the roads. Through faster detection of incidents in road traffic, it is possible to decrease or completely avoid congestion. If congestion can be avoided, secondary accidents can also be reduced, for example at the end of a congestion.

In addition, incidents can be resolved more quickly and thus traffic can flow more quickly. Furthermore, it is possible to distribute traffic strategically and to achieve a homogeneous traffic load on the road network by means of an area-wide automated traffic management.

More automation and the availability of comprehensive data about the road network bring the opportunity to better integrate and connect TMC operations with fleet management operations.

4.1.4. THREATS

To analyse the threats of an increased automation in traffic management centres, the following questions are discussed:

- What obstacles do you have in the deployment of automation in traffic management?
- Is changing technology threatening jobs?
- Financial issues - and how to solve? How to prioritize?
- Could any of the identified weaknesses seriously threaten business?

A non-exhaustive selection of threats is shown in Figure 4.4.

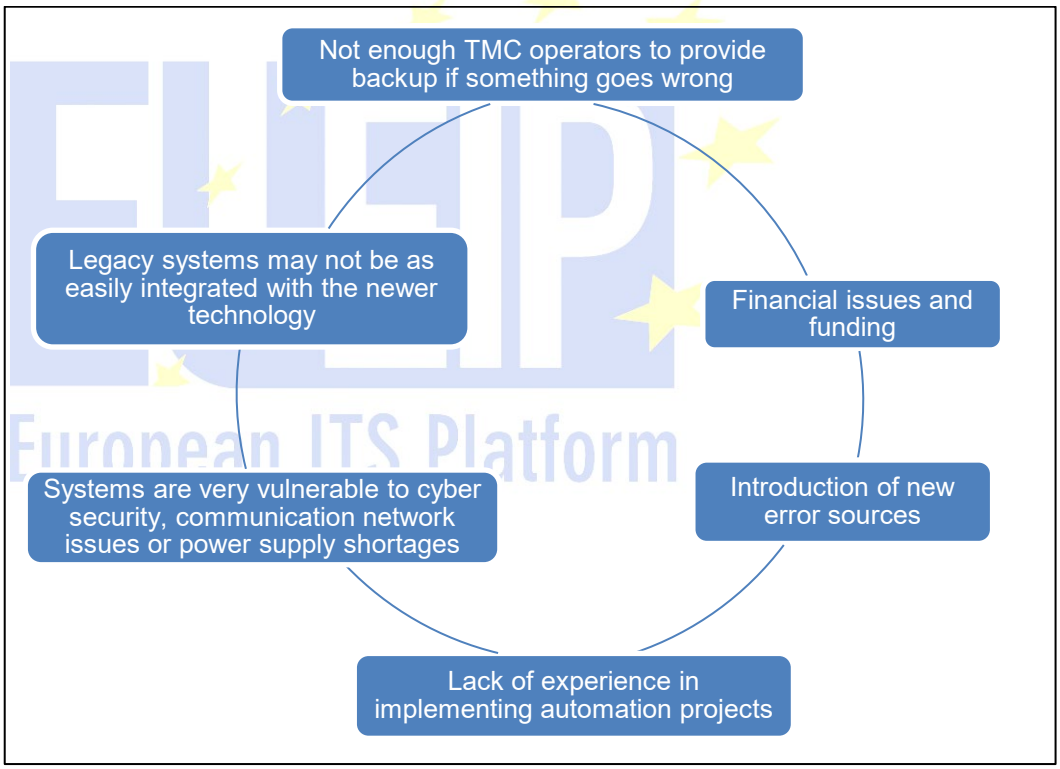

Figure 4.4 Threats for automation in TMCs

The increasing automation in traffic management is a potential threat for the availability of TMC operators. If more and more tasks are taken over by technology, fewer human operators are needed. This is a positive effect when the system functions properly. But if the system fails, there will not be enough operators to keep the TMC running.

The automation of TMCs can be associated with a high financial effort for the road operator. In order to advance the automation of traffic management, the road operator must first invest in the digitalisation of the traffic infrastructure. Once the road infrastructure is equipped with the appropriate technology, it is necessary to maintain the technology.

Furthermore, the multitude of interfaces of the respective infrastructure components could create new sources of error, which could considerably complicate the functionality of the overall system.

4.1.5. CONCLUSION

The SWOT analysis shows that the automation of traffic management centres involves many different aspects. On the one hand, the digitalization of the road infrastructure is associated with high financial expenditure and a threatening cyber security issues, but on the other hand, this development makes it possible to collect traffic data faster and holistically and thus reduce, for example, congestions. In this way, the road operator is expanding its user-oriented competencies as a service provider. In conclusion, the strengths and opportunities exceed the risks and weaknesses in the automation of traffic management centres.

4.2. Implementation roadmap

The main objective of this chapter is to foresee an implementation roadmap for automation of road operator ITS that could bring the identified benefits in a reasonable time span, building on the existing implementations and expected developments.

Based on our research, we did not identify any other studies dealing with the increased automation and autonomic functionality of road operator ITS. However, it became obvious that the emergence of automated vehicles and C-ITS will be a major incentive for automation of TMC operations. Hence, the multiple existing roadmaps for automated driving development were taken into account and especially the most recent one from ERTRAC (2019). In addition, we took into account the results of a survey performed by Activity 4.3 of EU EIP, which shows that there is a 5-10 years cycle of upgrading existing ITS infrastructure.

As a result, we set the target for the roadmap to 2030 with three milestones in 2021, 2024 and 2027. We consider 2030 to be the target point of a 10-year period when, pressured by developments in automated vehicles and C-ITS, road operators need to upgrade their systems while at the same time the market penetration of automated and especially connected vehicles will reach considerable levels. And, by that time, we believe most European road operators also recognize the benefits of increased automation and will consider implementing autonomic functionalities as part of the upgrade. Finally, as the penetration of automated vehicles is expected to rapidly increase towards the end of the period, we believe another upgrade of TMCs can be done by that year with an even stronger focus on fully autonomic behaviour.

The foreseen implementation objectives are presented in Figure 4.5.

The first period in the roadmap is from present to 2021. In this timeframe it is expected that mostly the hardware level will increase its automation. As such all TMCs will have complex asset management systems for all components. More than 90% of hardware components sold on the market should be capable of monitoring their status and generating alarms. Also, most of the hardware components should be plug-and-play. At the same time, existing traffic management basic operations (e.g. variable traffic control, traffic and weather monitoring, etc.) will be enhanced and new ones will be introduced towards having at least half of the operations automated, with or without operator intervention for validation.

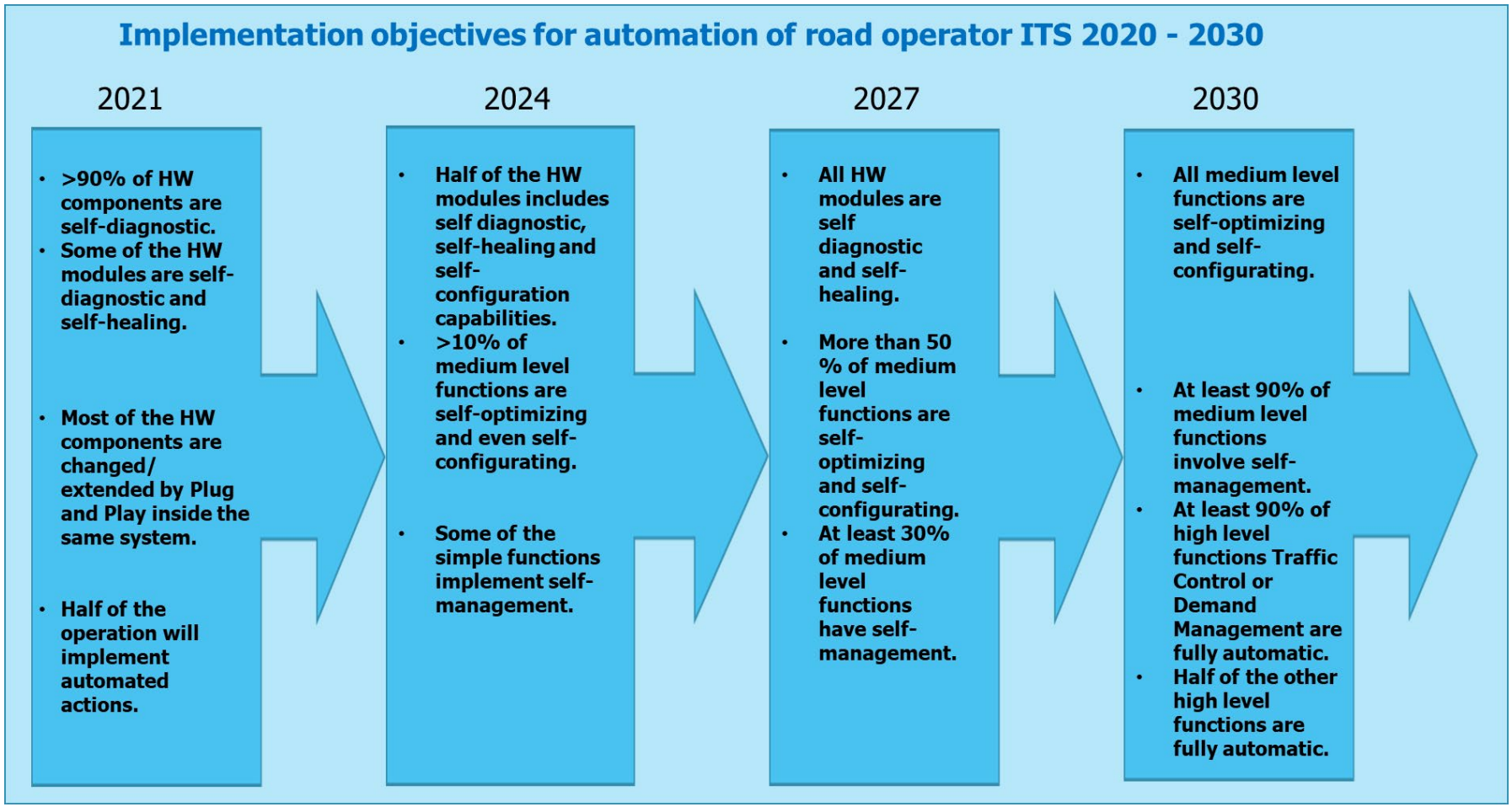

Figure 4.5 Implementation objectives for automation of road operator ITS

From 2021 to 2024, the automation focus should start shifting from hardware to system functions (e.g. queue protection, dynamic lane management, weather information, etc.). In terms of hardware, more than half of the modules would be capable of self-diagnostic, self-healing and self-configuration without human intervention in at least in 95% of cases. With reference to the functional architecture introduced in this report, by 2024 more than 10% of the medium level functions would be capable of self-optimizing and self-configuration. Some of the simple functions should have self-management properties, even without operator intervention.

Starting from 2024 and until 2027 all hardware modules installed would be capable of self-diagnostic and self-healing at least in 95% of cases without human intervention. The proportion of medium level functions capable of self-optimizing and self-configuration would increase to more than 50%. Also at least 30% of the medium level functions would be capable of self-management.

Starting from 2027 to 2030, we could expect that all medium level functions are capable of self-optimizing and self-configuration. In addition, almost all medium level functions include self-management capability, at least in terms of management of the system itself. As mentioned before, the self-management autonomic function includes three sub-functions of management of the system itself, management of the traffic, and management of operational activities. It is likely that the application of self-management will follow that order. However, in some medium level operational functions, the management of traffic or even management of operational activities could be realized before the management of the system itself. This has already been the case e.g., for remote controlled traffic signal systems or some tunnel management systems. During the period we could also expect to have at least 90% of the systems full autonomic properties in two high level autonomic functions of the ITS (presented in Chapter 3.2), either Traffic Control or Demand Management, and being able to provide services without operator intervention in almost all situations. In addition, half of the other high level autonomic functions of the ITS mentioned earlier in the report in Chapter 3.2 will be fully automatic.

The conclusions of the road map to the actual actions proposed to be carried out by the road operators are summarized in Figure 4.6.

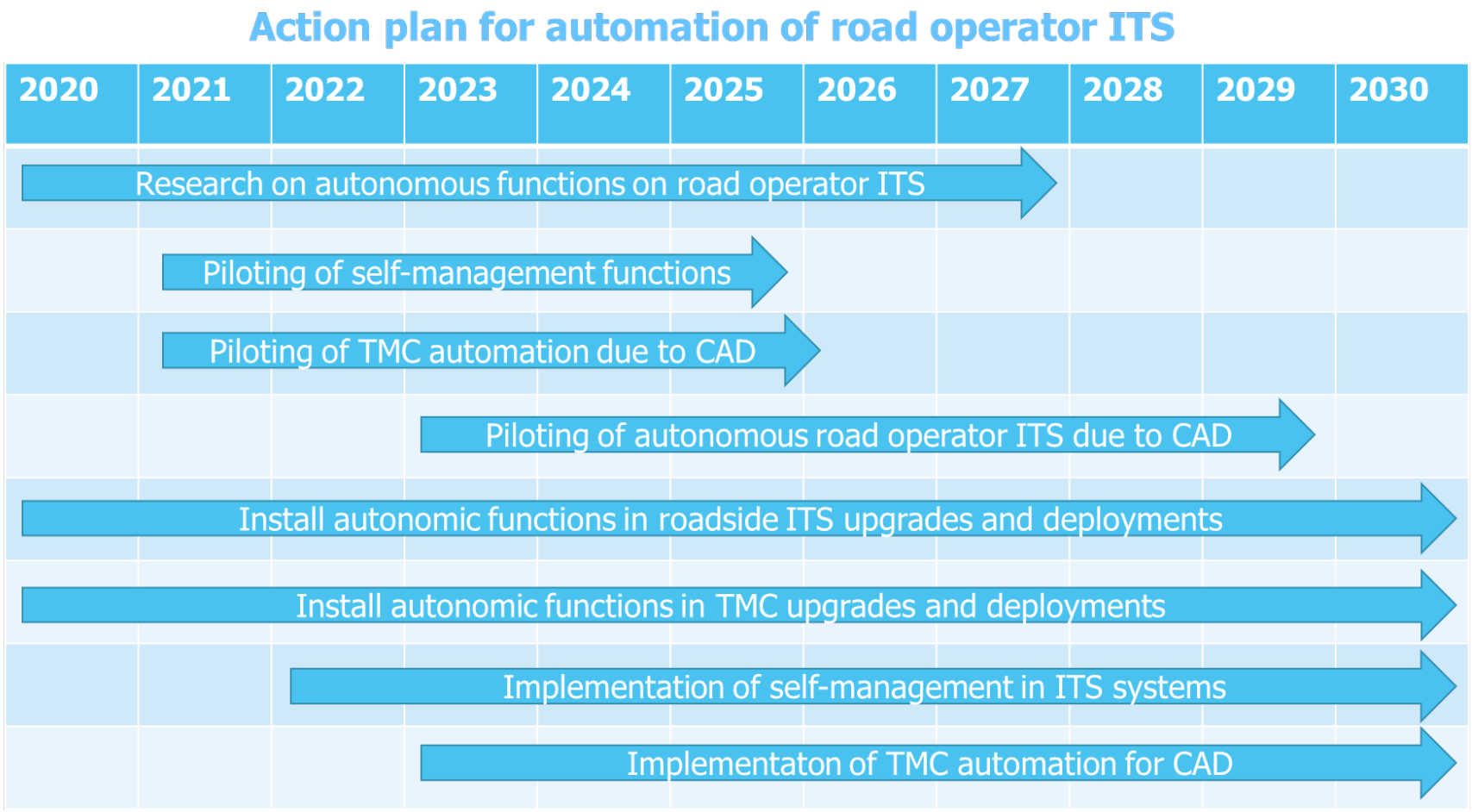

Figure 4.6 Proposed action plan for automation of road operator ITS

The research on autonomic functions of road operator ITS needs to be continued. Key topics are:

1) to improve the quality of data collection and fusion on traffic and road environment so that the autonomic functions can operate in a safe and reliable manner without the need of human intervention, and
2) the development of AI software for autonomic functions, and especially self-management.

The implementations should be prepared by piloting, starting with self-management functions and the TMC automation efforts required to accommodate the traffic management of connected and automated vehicles. These pilots should be followed by implementations of the wider traffic management automation actions needed for dealing with connected and automated vehicles including the liaison with the fleet management and supervision centres of the automated vehicle fleet operators.

Piloting also supports building up the expertise of the personnel at traffic management centres and in the road operator organisations regarding automation. Such expertise and capabilities are essential for the utilisation of the autonomic functions.

The deployments should be continuous regarding the autonomic functions. The ones that have been proven to work in an appropriate manner with sufficient economic feasibility should be routinely installed when deploying new ITS or upgrading existing ITS both by the roadside and in traffic management centres.

The traffic management systems involving self-management functions are expected to be deployed after 2022. The implementation of traffic management centre automation should start shortly afterwards.

European ITS Platform

5. Measuring the effects of increased automation

5.1. Key performance indicators

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

Both the KPIs and their targets are based on the analysis of the existing implementations and the expertise of the authors. They are not meant to impose any mandatory requirements on the implementers of TMCs, but rather provide an expert advice on assessing the benefits and return of investment of introducing automation into daily operations.

In defining the KPIs, the SWOT analysis and implementation roadmap described in Chapter 4 were taken into account. Also, the KPIs proposed initially in [4] were amended considering developments in the field and the results of the workshop on the topic "Automation in Traffic Management and Traffic Centres: Experiences and Plans" held by EU EIP Activity 4.2 during the EU EIP Forum on 14 November 2018 in Utrecht.

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

KPD1 and KPD2 are quite self-explanatory. KPD3 helps to 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.

KPD4 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.

KPD5 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.

KPD6 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 per operational function of the TMC
- KPO2 – % reduction of operator man-hours for traffic management centre operations with reference to the introduction of the automation
- KPO3 – % reduction of average delays/decision times per operational function of the TMC with reference to the values of non-automated TMCs (level A0 and 0 on our automation scales)[1]
- KPO4 – % of automatically detected incidents (compared to the ones by human operators)
- KPO5 – % reduction of average latency (time needed) from incident detection to traffic information with reference to the values of non-automated TMCs (level A0 and 0 on our automation scales)
- KPO6 – % reduction of average latency (time needed) from incident detection to traffic management operation with reference to the values of non-automated TMCs (level A0 and 0 on our automation scales)

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.

[1] Automation scales defined in [2] and included in Annex 1

5.2. Proposal for implementation targets

Based on the expert knowledge of the involved partners and the analysis of the existing implementations, this chapter proposes target values for the defined KPIs in the implementation of TMC systems for the year 2021 horizon. The values also consider the results of the EU EIP Activity 4.2 workshop organized during the EU EIP Forum on 14 November 2018 in Utrecht.

These year 2021 horizon implementation targets are intended for systems planned to be implemented up to that year. Besides that, in correlation with the roadmap presented in Chapter 4.2, the target values to be reached by 2030 are proposed as well.

The table below presents the proposed targets for deployment KPIs.

Table 5.1 Target values for deployment KPIs

Deployment KPI	Year 2021 implementation target	Target value for 2030
KPD1 – % of hardware components with automated alarms	70%	95%
KPD2 – % of hardware modules capable of self-diagnostic and self-healing at least in 95% of cases without human intervention	50%	100%
KPD3 – number of performed automated actions/hour	30	60
KPD4 – % of traffic information messages updated automatically out of the total messages updated per day	25%	85%
KPD5 – % of traffic information provided automatically per type of information	30%	85%
KPD6 – % of ratio of automated/manual road work/other maintenance operations planning for main motorway network	60%	98%
KPD6 – % of ratio of automated/manual road work/other maintenance operations planning excepting main motorway network	30%	70%

The table below presents the proposed targets for operations KPIs.

Table 5.2 Target values for operational KPIs

Operational KPIs	Year 2021 implementation target	Target value for 2030
KPO1 – % share of correct automated actions versus all proposed automated actions per operational function of the TMC	70%	98%

KPO2 – % reduction of operator man-hours for traffic management centre operations with reference to the introduction of the automation[2]	15%	50%
KPO3 – % reduction of average delays/decision times per operational function of the TMC with reference to the values of non-automated TMCs (level A0 and 0 on our automation scales)	10%	50%
KPO4 – % of automatically detected incidents (compared with the ones by human operators)	50%	90%
KPO5 – % reduction of average latency (time needed) from incident detection to traffic information with reference to the values of non-automated TMCs (level A0 and 0 on our automation scales)	20%	80%
KPO6 – % reduction of average latency (time needed) from incident detection to traffic management operation with reference to the values of non-automated TMCs (level A0 and 0 on our automation scales)	10%	80%

[2] The targets reflect a gradual increase of effectiveness: in 2021 introduction of automation would only give a 15% reduction (not necessarily in the first year after the implementation) while in 2030, if a centre switches from non-automation to automation, it would get a 50% reduction

6. Conclusions

The scope of this report was to describe how autonomic functions could benefit road operators in improving their operations, maintenance and provision of ITS services. The document starts with the existing autonomic functions and systems and proposes a new approach in terms of architecture and the implementation of the autonomic applications.

Autonomic systems are closely related to the broader field of Artificial Intelligence which covers software and hardware systems that exhibit human-like capabilities in terms of learning, situation awareness, interaction and problem solving.

This document follows the work done in the previous reports “Autonomic functions implemented in existing ITS (status update 2019)” [2], “Needs for autonomic functions in road operators' ITS” [3] and “Good and bad practices from increasing the automation of road operators' ITS - Lessons learned” [4] which explained autonomic behaviour and functions and also presented existing road operator systems with automated and autonomic-related functionality as well as lessons learned from implementing autonomic functions on roadside and traffic management centre systems.

Chapter two focused on presenting how major needs of road operators can be supported with autonomic functions of ITS systems. In many European countries traffic centres are faced with multiple challenges in their daily operations. As the tasks increase and become more complex, there is a high need for increased automation that could provide solutions for many of their needs, like:

- decrease operator workload without increasing the number of operators
- faster reaction times and minimize the downtime of the operations in case of malfunctions
- reduces the effort for human operators to collect traffic data and provide traffic information
- less effort in planning road works
- better data integration between the systems and increased overall system efficiency.

Chapter three looked at the evolution of ITS functions towards autonomic functions and proposed a functional architecture of a TMC. The focus was mostly on TMC services selected in [2]. The architecture was divided in high level and medium level functions and described how autonomic properties could be positioned at each level.

Chapter four started with a SWOT analysis of introduction automation in TMC. The general conclusion of the analysis is that automation in TMCs brings significant benefits that outweigh the implementation costs. This chapter also proposed a roadmap up to 2030 for the implementation of automation in the current and future TMCs. The main conclusion from the roadmap is that the deployments should be continuous with regard to the autonomic functions. The ones that have been proven to work in an appropriate manner

with sufficient economic feasibility should be routinely installed when deploying new ITS or upgrading existing ITS both by the roadside and in traffic management centres.

The last chapter proposed a set of KPIs that can be used to measure the effects of introducing automation and autonomic functions. Also, targets for those KPIs are introduced for two foreseen time horizons: 2021 and 2030. Both the KPIs and their targets are not meant to impose any mandatory requirements on the implementers of TMCs, but rather they provide an expert advice on assessing the benefits and return of investment from introducing automation into daily operations.

References

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Annex 1. 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.