Contents

Autonomic Systems: A transportation perspective

Road Transport Support (RTS) systems, and especially the application of ICT to RTS in the form of Intelligent Transportation Systems (ITS), have been used with a certain amount of success over the past 30 years. Road transport research and development programmes have led to major advances within ITS. Currently, a mix of infrastructure is used to alleviate road congestion; however, modern systems have been linked to “technological giants with a child’s brain”.

As the complexity of systems grows, the need to build into them the means to manage and maintain themselves becomes necessary, particularly in the case of large scale, heterogeneous, distributed control systems. Systems need to be self-directing, self-configuring, self-maintaining, self-protecting and self-optimising. One consequence of self-managing systems is that their interaction with people is set more at a “service” level than a “command” level. As a result, a traffic control centre manager will interface with future autonomic systems by communicating goals, priorities and tasks which the systems will solve.

This section will investigate how best to integrate current technology and ITS research with ARTS. First we start with how AI in general has been used in ITS, then look specifically to autonomy in specific areas of ITS.

Chapter 1

Architectures

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1.1 The architecture of autonomic intelligent transport systems

1.1.1 Introduction

For this chapter we have to define three different layers for approaching the system. The intelligent transport system is a generic system for traffic management, traveller information, fee collection etc. and, for this system, following layers could be defined:

1. Service layer - this means the level of ITS services which are provided by the system as response at user needs.
2. ITS system layer - this level is focused on description of main subsystems and components of the system which are the main support in providing ITS services.
3. Solutions and technologies layer - at this level the technical solutions, for each subsystem or component, are revealed.

The process for defining the technological solutions is formed by the next steps:

Figure 1.1: Multilayer approach of autonomic ITS systems.

- Identification of users and stakeholders.
- Collection of users and stakeholders needs.
- Definition of ITS services which are provided by the system to fulfil the needs.
- Elaboration of ITS architecture: functional and physical view points.

Identification of each particular technical solution to provide a function of the system The analysis could be done from the users aspirations to technological solutions top-down (the system is designed as a demand of users), from technological solutions to users bottom-up (that means education of users) and a mixture of both, starting with the identification of user needs.

1.1.2 Types of system architectures

Descriptor: sub-task 2.1 is focused on the architecture of complex systems and the types of these architectures as a main tool for understanding the systems

System architecture is a high level vision of the system which is dealing with the description of the components, the relations between them and the behavior of each component as part of the system. Systems Architecture is a response to the conceptual and practical difficulties of the description and the design of complex systems.

Systems Architecture is based on 9 fundamental principles:

- the objects of the reality are modeled as systems
- a system can be broken down into a set of smaller subsystems
- a system must be considered in interaction with other systems
- a system must be considered through its whole lifecycle
- a system can be linked to another through an interface
- a system can be considered at various abstraction levels
- a system can be viewed according to several layers
- a system can be described through interrelated models
- a system can be described through different viewpoints corresponding to various actors concerned by the system

Figure 1.2: Context diagram FRAME.

Figure 1.3: Functional architecture for Traveler Information

1.1.3 ITS Architectures

Descriptor: the main objective of this sub-task is to identify the main directions in developing framework architecture and architecture for intelligent transport systems

For ITS domain we can define two kinds of architecture: framework architecture and specific system architecture. An ITS architecture is the conceptual design that defines the structure and/or behavior of an integrated ITS. FRAME Architecture user needs and the methodology to link the user needs and the functions of the system

The approach in FRAME architecture is to consider the system in its context and to identify any external body which is dealing with providing and collecting data to/from the system. Every external body is named terminator as an end of the system and all these terminators can define the behavior of the system.

In Figure Context diagram FRAME it is presented a context diagram of an intelligent transport system in which we can identify the terminators of the system (in this example, there is a general context diagram with all terminators they have already identified).

Another important step in developing and ITS system is to create its functional viewpoint as part of its architecture.

In Figure, it is shown a functional view point of Traveler Information service which is formed by functions and data flows (which are needed between functions and/or between functions and terminators). Other important steps in developing an ITS architecture, as a framework for system development, were done in US and they elaborate a framework architecture as well as a software tool for ITS architecture creation.

They have identified four major components of the system which are involved in:

- travellers

Figure 1.4: US National ITS Architecture

Figure 1.5: Architecture view in US.

Figure 1.6: Communication architecture in cooperative systems CVIS.

- centres
- vehicles
- field

All these components are linked together through communication infrastructure. In Figure , National ITS Architecture in US, they have used a multilayer approach for the ITS systems and services. That means, an institutional layer which will use the architecture to define user services, to plan and for project development, a transportation layer, which is related to logical architecture, data flows, physical architecture, security and service packages, and the communications layer which is dealing with standards.

Another important approach in ITS which so close to autonomic system is cooperative systems. Communication architecture (Figure) defined in CVIS project has underlined the need for self - * properties to facilitate the cooperation between vehicles and infrastructure (v2i) as well as vehicles and vehicles (v2v) or a mix of them (x2x). The main characteristic of these systems are to facilitate the cooperation between different systems in terms of providing ITS services.

The project CVIS has defined the cooperative properties of the systems in terms of considering vehicle in the relation with its environment.

The components of CVIS cooperative system will integrate the vehicle in its environment and will provide services in a cooperative manner.

1.1.4 Autonomic systems architecture

Autonomic computing seeks to improve computing systems with a similar aim of decreasing human involvement. Autonomic computing attempts to intervene in computing systems in a similar fashion as its biological coun-

Figure 1.7: The components of CVIS cooperative system

Figure 1.8: Autonomic computing reference architecture.

Figure 1.9: IBM's reference model for autonomic control loops.

terpart. In my approach I consider that autonomic behaviour could be implemented in two manners:

- Through existing ITS architecture and systems, we can add managers for autonomic properties and the system can become autonomic;
- Developing an Autonomic ITS system which is designed as an autonomic system and has all these self-*properties inside.

In the reference architecture for autonomic computing elaborated by IBM (Figure) the main idea is to manage the computational resources in an autonomic manner. That means a development of autonomic managers which are able to manage all these resources. The idea of autonomic managers could be extended from no human intervention to no other system intervention.

An autonomic control loop has 5 components:

- **Monitoring** - a sensor (which is in contact with the phenomenon or process) facilitates data collection to define a model of thing which is monitoring. The result of this activity is a symptom. This activity generates inputs to knowledge.
- **Analyzing** - the symptom is analyzed and based of knowledge the model which is constructed with collected data is comparing with an ideal model and a change request is generated.
- **Planning** - a change plan is elaborated based on change request
- **Executing** - the plan is realizing using an effector which can affect the phenomenon or process.
- **Knowledge acquiring** - all previous components are involved in acquiring knowledge to improve the behavior of the system.

Automated planning could offer the possibility to implement self* properties for an autonomic system. General architecture of planning is described in Figure .

This automated planning architecture could be integrated in an ITS system architecture in terms of changing the approach and to up more technological characteristics to functional viewpoint of the system.

Figure 1.10: General architecture of automated planning.

Chapter 2

AI for ITS, Intelligent transportation

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2.1 Introduction

The goal of Intelligent Transport Systems (ITS) in road transport is to achieve improvements in mobilty, safety and the productivity of the transportation system through the integrated application of advanced monitoring, communications, computer, display and control process technologies, both in the vehicle and on the road [6].This includes stand-alone applications such as traffic management systems, information and warning systems installed in individual vehicles, as well as cooperative ITS (C-ITS) applications involving vehicle to infrastructure and vehicle to vehicle communications. The transport management includes tasks for example: Traffic and Route Guidance Control, Decision making, Planning process, Forecasting, Optimisation. An artificial intelligence (AI) has its important place in Intelligent Transport Systems (ITS) [56]. They have overcome the limitations of traditional mathematical methods regarding misspecification, biased outliers and assumptions. AI techniques are appealing due to their flexibility, adaptability, possibility of innovation and to the fact that they are able to circulate and process highly dimensional, large sets of data. Artificial Intelligence techniques are being incorporated into intelligent traffic management models which are capable of analysing traffic behaviour and evolution in a similar way to an expert traffic controller. AI techniques are being applied in dynamic traffic management including evolutionary algorithms, knowledge-based systems, neural networks and multiagent systems [63]. Incident management is an integral part of transport network management and AI techniques are helping to detect, monitor and respond to accidents quickly. Electronic payment and smart cards are already in use for payment of public transport fares and road tolls around the world. An artificial Intelligence can be used in road weather management, commercial vehicle operations and intermodal freight [30]. Bayesian network theory ([50], [**?**]), Neural networks [**?**], Kalman filtering algorithm [9] have been widely used for traffic speed prediction. Traffic condition prediction and Traffic Flow Forecasting have become the hotspots in ITS. Simulated Annealing model and Particle Swarm Optimization (PSO) technique in combination with different neural networks can be used for the prediction of urban traffic flow [38].

2.2 Fuzzy systems in Intelligent Transport Systems

Fuzzy logic is a powerful technique for controlling processes that are difficult to model and linearize. Fuzzy logic control strategy has been proposed for vehicle position and speed control or collision avoidance or controlling the flow. One of the applications of ITS is to provide the assistance to the control of some of the vehicle elements, like the throttle pedal and consequently, the speed-control assistance. Adaptive cruise control (ACC) system can automatically adjust the speed in order to maintain a proper headway distance (gap) between vehicles in the same lane. Because of the ability of fuzzy logic controller (FLC) in mimicking human behaviour, it can be used as a good bridge to achieve this goal. In paper [41], the proposed ACC algorithm and designed FLC structure was investigated through MATLAB simulations, but it will be applied in real vehicles. The proposed algorithm can be used in safe distance keeping observers, collision avoidance systems, assistant driving devices and other ITS applications. Collision avoidance is one of the most difficult and challenging automatic driving operations in the domain of intelligent vehicles. In emergency situations, human drivers are more likely to brake than to steer, although the optimal maneuver would, more frequently, be steering alone. This statement suggests the use of automatic steering as a promising solution to avoid accidents in the future. The paper [32] has described an automatic driving system that can carry out autonomous pedestrian collision avoidance by steering. The collision avoidance maneuver is performed using fuzzy controllers for the actuators that mimic human behavior and reactions, along with a high-precision Global Positioning System (GPS), which provides the information needed for the autonomous navigation. Although the proposed approach provides very encouraging results, from a real-world application perspective, where the traffic conditions are certainly more complex, significant effort is further necessary to solve this important problem including real urban traffic scenarios. To overcome traffic problems in large cities, an intelligent traffic control system is presented in [33]. It is based on the measurement of traffic density on the road using Morphological edge detection and fuzzy logic technique. Crossroads are one of the major problems in controlling the flow of vehicular traffic in urban environments [36]. A low-cost system using a DGPS and Wi-Fi communications was installed in a commercial car to permit information exchange by V2V communication. A fuzzy controller was aimed at managing traffic flow at crossroads in real time in response to the actions that other cars are taking. Experiments to check the behavior of the system with two vehicles, i.e., one manually driven and the other fully automated with the designed system installed, gave excellent results. The next steps in this research will focus on the inclusion of more vehicles at the crossroad, including more autonomous vehicles to test the response of the controller.

2.3 Neural networks in Intelligent Transport Systems

The field of transportation studies has in recent years seen an increased interest in neural network applications due to the inability of traditional methods to address the complexity of road traffic characteristics and relationships [51]. Results that are comparable or better than that obtained using mathematical models?typically statistical regression models - have thus been achieved using neural networks in areas such as driver behavior prediction, road payment maintenance, vehicle detection and classification, congestion detection, traffic control analysis, and intelligent transmission control ([3], [73], [75], [5], [28], [68]). Traffic flow prediction aims at estimating the number of vehicles given a specific region and a time interval, which is an important problem to address in transportation management ([24], [43], [72]). Reliable, accurate, and consistent real-time traffic flow prediction should support:

1. real-time route guidance in advanced traveler information systems for saving time and money;

2. reliable traffic control strategies in advanced traffic management systems for reducing traffic congestion and accidents; and

3. the evaluation of these dynamic guidance and control strategies [78].

Much research has been focused on this subject in recent years. Existing traffic flow prediction approaches can be divided into three categories.

1. Time-series approaches [65], [7], [62]. These approaches, such as the autoregressive integrated moving average (ARIMA) model [64] that

is extended from the autoregressive?moving average (ARMA) model with an extra procedure of difference, focus on finding the patterns of the temporal variation of traffic flow and then use that information for prediction.

2. Probabilistic graph approaches [60], [61] [74]. The modeling and forecasting of traffic flow is done from a probabilistic graph perspective, such as a Bayesian network, a Markov chain, and Markov random fields (MRFs).

3. Nonparametric approaches [10], [14], [57], [58]. Researchers demonstrated that nonparametric approaches generally perform better due to their strong ability to capture the uncertainty and complex nonlinearity of a traffic time series. Some representative methods are artificial neural networks (NNs) [58], [11], support vector regression (SVR) [10], and local weighted learning (LWL) [57].

In paper [77] the recursive traffic flow prediction algorithm using NNs was presented. The system prediction model is specified based on the understanding of how disturbances in traffic flow are propagated. The prediction is made at one-time step horizon of 30-s duration. The practicability of using such short prediction horizons or the effect of increasing the time step size was not considered. In a study [71] by Yasdi, the effectiveness of a NN model for prediction of traffic volume based on time series data is presented. A dynamic NN, namely a Jordan?Elman recurrent network, was employed in this study to predict weekly, daily, and hourly based traffic volume. Fu and Rilett in [31] presented an NN-based method for estimating route travel times between individual localities in an urban traffic network. The methodology developed in this study assumes that route travel times are time-dependent and stochastic and their means and standard deviations have to be estimated. In a study [23] by Ishak et al., an optimized NN-based methodology for short-term prediction horizons of traffic conditions was presented. It was found that the performance of different NNs families can be improved if traffic conditions and the number and type of the input parameters are considered. Up to 20-min point speed predictions are performed using the real traffic data and significant improvements were demonstrated. The paper [22] presentes a deep architecture for traffic flow prediction, which has been implemented as a stack of restricted Boltzmann machines (RBMs) at the bottom with a regression layer at the top. The stack architecture at the bottom is a deep belief network (DBN), and it is effective for unsupervised feature learning. To incorporate multitask learning (MTL) in the deep architecture, a multitask regression layer is used above the DBN for supervised prediction. To take full advantage of weight sharing in the deep architecture, a grouping method based on the weights in the top layer was presented to make MTL more effective.This is the first work employing deep learning in the transportation area. The positive results demonstrate that deep learning and MTL are promising in transportation research.

2.4 Evolutionary Approach to Intelligent Transport Systems

Today more and more Intelligent Transportation System (ITS) strategies such as High Occupancy Toll (HOT), Ramp metering, Route optimization, variable speed limits, etc., are introduced nationwide to reduce congestion and maintain desired service levels on the freeway. Optimization of all the different parameters in such strategies is vital to manage the traffic effectively [19]. In paper [48], the method of optimized routes using genetic algorithms techniques was presented. The main goal was to implement a method to obtain the best possible route between two points on a real road map, which will be included, as optimization module, in a fleet management system. The first approach to solve this problem was, basically, to solve the shortest path problem (SPP) between two points. Nevertheless, to obtain an optimized route in a road network is a more complicated problem. The developed method offers some advantages over mathematical algorithms that solve more complex problem than the SPP, as it takes less memory resources, and also, it presents more flexibility to changes in the restrictions applied to the road segments. This paper [25] describes a practical dynamic route planning method using real road maps in a wide area. The maps include traf?c signals, road classes, and the number of lanes. The proposed solution is using a genetic algorithm adopting viral infection. When traf?c congestion frequently changes during driving, an alternative route can be selected using viruses and other routes in the population in a real time. Experiments in dynamic environments using a real road map with 28000 cars show that the proposed method is superior to the Dijkstra algorithm for use in practical car navigation devices. Zhang and Xie used GAs to improve the predictive abilities of NNs for detection of accidents at signalized intersections in real time [79].

2.5 Hybrid Artificial Approach to Intelligent Transport Systems

Fuzzy neural networks, which combine the complementary capabilities of both neural networks and fuzzy logic, thus constitute a more promising technique for modeling traffic flow. A possible solution are in the case of traffic flow and driver behavior modeling, developing analysis, establishing geometric design criteria, selecting and implementing traffic control measures, as well as evaluating the service quality of transport facilities or model of traffic patterns. Fuzzy neural networks, which combine the capabilities of both neural networks and fuzzy logic, are seen as a very promising technique for automatically deriving from experimental data an approximate rule-based model. The paper [52] has described a novel approach to traffic flow analysis and prediction using a specific class of fuzzy neural network known as the POPFNN-TVR. The system was successfully trained and subsequently used for short-term traffic flow prediction. Experimental results have demonstrated the ability of POPFNN-TVR to extract a valid set of fuzzy rules from the training data as well as to generalize and react appropriately to new input data. Comparative analysis has demonstrated that POPFNN-TVR possesses a higher degree of prediction capability than a conventional feedforward neural network using backpropagation learning (FFBP).

2.6 Agent-based Approaches to Intelligent Transport Systems

Dia in [18] applied agent-based method (ABM) to analyze the effects of advanced traveler information systems on traffic congestion to evaluate the impacts of providing drivers with travel information. He applied discrete choice models to behavioral data to determine agent characteristics, and the agents? route-choice behavior was based on these frameworks. The model yielded promising results for more sophisticated ABMs in this domain. Hidas in [21] describes Simulation of Intelligent TRAnsport Systems (SITRAS), an agent-based traffic simulation. SITRAS is designed to provide a test-bed for ITS technologies to evaluate situations, such as driver response to incidents, which are not feasibly tested in the real world. He describes an agent-based approach to modeling lane changing behavior in congested conditions. Specifically, the model demonstrates that simulation of forced lane changing behavior is required for a realistic representation of traffic when an incident occurs. Peeta et al. model the interaction between cars and trucks to examine the effects of changes in car-following and lane-changing behavior on aggregate flow [47]. They use the results of stated preference surveys to characterize the behavior of non-truck drivers in the vicinity of trucks. The model allowed the authors to investigate the effects of mitigation strategies for car truck interactions, and they conclude that for the best combination of safety, traffic flow, and cartruck interactions, restricting trucks to the right lane is preferred. Balmer et al. describe MATSIM, a more recently developed large-scale agent-based traffic simulator [8]. The concept of agents has been used in transportation not just for modeling but also for control. Software agents are designed to function autonomously and control tasks. For example, Choy et al. in [13] and Manikonda et al. in [35] use software agents to optimize traffic signal timing.

2.7 Advanced implementations in ITS

The overall function of ITS is to improve decision making, often in real time, by transport network controllers and other users, thereby improving the operation of the entire transport system. In this paragraph, some actual implementations in ITS that display intelligent functions are described. For example, Satellite Navigation Technology Applications, Automatic Number Plate Recognition (ANPR) and Urban Traffic Management Systems (UTMS).

2.7.1 Intelligent Navigation Applications for ITS

A satellite navigation system with global coverage may be termed aglobal navigation satellite systemorGNSS [55]. The first system was the Global Positioning System (GPS) developed for use by the US military. The American NAVSTAR (Navigation Signal Timing and Ranging) GPS system is well established, initially consisting of a constellation of 24 satellites, which have been in operation since 1993, the same year in which free worldwide civilian use of GPS was sanctioned. The Russian GLONASS system (it has 16 operational satellites), a hybrid EU system (EGNOS) has been developed as a precursor to the Galileo project. The European Geostationary Navigation Overlay System (EGNOS), is a system of satellites and ground stations which are designed to improve the accuracy of the current GPS and GLONASS systems in Europe [20]. Satellite navigation receivers reduce errors by using combinations of signals from multiple satellites and multiple correlators, and then using techniques such asKalman filteringto combine the noisy, partial, and constantly changing data into a single estimate for position, time, and velocity. The combination GPS/INS integrated navigation system due to their complementary characters in many aspects was presented in paper [?]. The Extended Kalman Filter (EKF) is introduced as the basic data fusion algorithm. Even less than 4 observable satellites can contribute to the integrated system. Especially 2 satellites can maintain the orientation errors at a reasonable level due to the benefit of the tight integration. Intelligent Navigation Systems support individual travellers (usually drivers) by providing information about the shortest possible routes, the actual traffic situation and alternative routes. AI technologies will also address the need for dynamic routing depending on information from traffic management centres and from other travellers. Route selection problems in Car Navigation systems (CNS) are search problems for finding an optimal route from an orginal point to a destination point on a road network. The most efficient one-to-many nodes shortest path algorithm is Dijkstra?s algorithm. For the one-to-one node shortest path problem, the leading algorithm is A*. Moreover in case of CNS, the shortest path may not be the best one from other considerations such as, traffic time, costs, environmental problems and many other criteria. It is a multicriteria route selection problem, which is well known NP-complete multiobjective optimization problems. In paper[26] the multi-objective genetic algorithm was considered as a mathematicla model for car navigation systems. The computational experiment showed the operation of the applied algorithm.

2.7.2 Automatic Number Plate Recognition (ANPR)

In last few years, ANPR or license plate recognition (LPR) has been one of the useful approaches for vehicle surveillance [46]. It is can be applied at number of public places for fulfilling some of the purposes like traffic safety enforcement, automatic toll text collection, car park system and Automatic vehicle parking system. ANPR algorithms are generally divided in four steps:

1. Vehicle image capture,

2. Number plate detection

3. Character segmentation and

4. Character recognition.

The first phase, i.e. to capture image of vehicle looks very easy but it is quite exigent task as it is very difficult to capture image of moving vehicle in real time in such a manner that none of the component of vehicle especially the vehicle number plate should be missed. The success of fourth step depends on how second and third step are able to locate vehicle number plate and separate each character. These systems are based on different methodologies but still it is really challenging task as some of the factors like high speed of vehicle, non-uniform vehicle number plate, language of vehicle number and different lighting conditions can affect a lot in the overall recognition rate. Most of the ANPR systems are based on common approaches like artificial neural network (ANN) [4], [27], [16], Probabilistic neural network (PNN) [81], Optical Character Recognition (OCR) [4], [80], Feature salient [12], Sliding concentrating window (SCW) [80],[16], support vector machine (SVM) [67], color segmentation [70], fuzzy based algorithm [66], scale invariant feature transform (SIFT) [76], trichromatic imaging, Least Square Method (LSM) [42],[17], online license plate matching based on weighted edit distance [40] and color-discrete characteristics [69]. ANPR can be further exploited for vehicle owner identification, vehicle model identification traffic control, vehicle speed control and vehicle location tracking. Most of the ANPR focus on processing one vehicle number plate but in real-time there can be more than one vehicle number plates while the images are being captured. ANPR is difficult system because of different number of phases and presently it is not possible to achieve 100% overall accuracy as each phase is dependent on previous phase. Certain factors like different illumination conditions, vehicle shadow and non-uniform size of license plate characters, different font and background color affect the performance of ANPR. Some systems work in these restricted conditions only and might not produce good amount of accuracy in adverse conditions.

2.7.3 Urban Traffic Management and Control (UTMC)

Traffic congestion is an increasing problem in towns and cities worldwide. Urban traffic control (UTC) systems are a specialist form of traffic management which integrate and co-ordinate traffic signal control over a wide area in order to control traffic flows on the road network. Integration and co-ordination between adjacent traffic signals involves designing a plan based on the occurrence and duration of individual signal aspects and the time offsets between them and introducing a system to link the signals together electronically. A traffic responsive signal control system is a means of adjusting the traffic signal settings (cycles, green splits and offsets), which optimise a given objective function, such as minimising travel time or stops, in real-time based upon estimates of traffic conditions [39]. UTC systems can provide the basis for an extended control system, generally termed urban Traffic Management and Control (UTMC). They include incorporating emergency service vehicles and priority for public transport such as bus priorities, and their integration with information systems such as variable message signs, real-time driver information systems and route guidance and parking guidance and information system. Traffic control strategies which fall mainly into fixed-time and traffic-responsive control have been innovated with various control and optimization methods with the aim to improve the traffic situations. Fixed-time strategy is a type of pre-timed signal control scheme that is computed offline. With the aid of simulation tools such as MAXBAND and TRANSYT; signal offset, cycle time and optimal splits are calculated using historical traffic data before implementation in real-time. On the other hand, traffic-responsive strategies employ sensors that collect real-time traffic data and utilize control schemes that change the splits, cycle time and offset at individual intersections and evaluate the best signal timing plan for the traffic situation. Fixed-time control methods mostly apply to isolated intersections while traffic-responsive strategies aim to provide a coordinated control effort that involves a few intersections and even the whole urban network. The traffic-responsive control methods are: Adaptive control schemes, Model-based methods and Store-and-forward approach. Adaptive control schemes such as Split Cycle Offset Optimisation Technique (SCOOT) and SCAT have been applied mostly in cities in the United Kingdom and Australia, respectively. They run in a central computer networked with sensors that feed real-time traffic data. Based on real-time data both schemes optimize cycle length, offset and phase split at individual intersections. It is found that SCOOT performances deteriorate in saturated traffic conditions. Other similar methods include UTOPIA and MITROP. Though model-based methods have contributed to significant improvements in reducing total time spent by vehicles in the network, the discrete variables in these models require exponential complexity algorithm for global minimization. Hence, the control strategy is not real-time feasible for more than one intersection and a decentralized scheme is needed to address this problem [44]. The store-and-forward approach simplifies programming effort as the traffic flow process is modelled with simpler mathematical model without discrete variables. The benefit of this method is the underlying optimization methods that can be applied with it [2]. It is reported that TUC (a type of store-and-forward control) leads to a 15 to 25% improvement in average network speed compared with pre-existing time-of-day plan [29]. However, regulation of traffic only allows for split optimization, while cycle time and offset must be delivered by additional algorithms [2]. RGDIS type of control is a novel approach that uses information system to influence driver route-choice behaviour but the impact of such approach is difficult to be quantified systematically and real implementations of iterative strategies are still in-progress due to the code complexity of the algorithm [45]. Besides developing less computational costly algorithm future research work should focus on developing driver and information communication technologies for RGDIS. Examples of such technologies are inter-vehicle communication [53] and Roncaili [59] which provide position-dependent real-time information to drivers.

2.8 Challenges and Actions for the Community

The past decade has seen the emergence of Intelligent Transport Systems (ITS), involving the integrated application of communications, control and information processing technologies to the transportation system. The new AI directions are needed to address the challenges and actions of ITS [63]:

New generation of integrated intelligent approaches as system solutions in real-time environment.

The experience shows that innovation amongst information services and network providers has generally outpaced innovation in all segments. As transportation problems become more multi-faceted, future ITS will contain heterogeneous distributed components and systems of large numbers that must work together effectively to deliver expected performance. A main challenge is implementation new generation of integrated intelligent approaches as system solutions in real-time environment.

Artificial Intelligent control systems .

Real-time simulation and optimization, artificial intelligence, model predictive control alongside with management of uncertainty in transport system simulation and modelling will lie at the heart of dynamic traffic management and will require ever increased levels of robustness and fault tolerance.We expect that the application of new forcasting and optimisation strategies and theirs hybrid models would improve prediction and optimisation accuracy of complex and dynamic systems.

Distributed Learning of systems .

Research in learning automata, neural nets, fuzzy systems, and brain models provides insight into adaptation and learning, and the similarities and differences between neuronal and electronic computing processes. Ramos et al. draws attention, that intelligence isn?t possible without knowledge [37]. Distributed Learning [15], learning of learnings systems (LOLS) is a challenge due to individual learning systems interacting with other members of the swarm in a collaborative environment. The objective of such learning is to improve the overall performance of the system. However, this is achieved only by improving each individual?s (subsystem) outputs [34]. We expect that future research will integrate the intelligence in all the components of the system: intelligent vehicles, an intelligent infrastructure, intelligent control system, intelligent commputers, intelligent cargo and intelligent enablers of information [1].

Embodied intelligence .

The intelligent transport agent will be designed in the context of the synthetic methodology, to be physical in the real world with high-level cognition. The approach of embodied intelligence will be shifted more towards ? non-human ? biological systems, but to the general issue of coupling biological and technical substrate (biological machines) [49].

Pro-active traffic management structure .
Future dynamic traffic management systems are required to support network-wide, pro-active traffic management structure, instead of the locally oriented, reactive traffic management [54] which is common today.

Chapter 3

Network Access & Mobile Technologies for Autonomic Transport Management

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3.1 LTE and LTE-A for Vehicular Networking

3.1.1 Introduction

With the huge proliferation of wireless technologies, mobile ad hoc networks have found widespread applications in the automobile industry. Nowadays, cars are equipped with different kinds of sensors, microcomputers, and wireless devices. This allows the formation of a new kind of mobile *ad hoc* network between the nearby moving vehicles or between vehicles and the roadside infrastructure (VANET - vehicular ad hoc networks). These networks are self-organizing and multihop and enable the exchange of data between the users in nearby vehicles.

With the help of these networks, intelligent transportation systems (ITSs) can be built that provide several benefits to users in terms of road safety, collision prevention, traffic scenario monitoring, congestion avoidance, infotainment, etc. Vehicular *ad hoc* networks are characterized by the high mobility of the vehicles, resulting in frequent and dynamic changes in the network topology. A number of interesting and desired applications of Intelligent Transportation Systems have been stimulating VANET technology. Many national and international projects in government, industry, and academia are devoted to vehicular networks. These include consortia like

Vehicle Safety Consortium (VSC) in the United States, the Car-2-Car Communication Consortium (C2C-CC), the ETSI-ITS in Europe, the Advanced Safety Vehicle Program (ASV) in Japan, and other standardization efforts like IEEE 802.11p (WAVE).

3.1.2 State of the Art

By integrating technologies for information and communications (ICT), ITS enable authorities, operators and individual travelers to make better informed and coordinated decisions. The above-mentioned concerns motivate the recent increasing interest in Long Term Evolution (LTE) as a potential access technology to support communications in vehicular environments. LTE is the most promising wireless broadband technology that provides high data rate and lowlatency to mobile users. Like all cellular systems, it can benefit from a large coverage area, high penetration rate, and high-speed terminal support. LTE particularly fits the high-bandwidth demands and QoS-sensitive requirements of a category of vehicular applications. Its capability to support applications specifically conceived for the vehicular environment to provide road safety and traffic efficiency services, is still an open issue. ETSI and ISO are currently investigating the LTE capabilities to support these cooperative applications.

IEEE 802.11p is the standard that supports ITS applications in Vehicular Ad hoc NETworks (VANETs). Due to its limited radio range and without a pervasive roadside communication infrastructure, 802.11p can only offer intermittent and short-lived V2I connectivity.

LTE and LTE-A are the main candidate access technologies which have different characteristics and can match the vehicular application's requirements, more or less effectively. In the regions completely covered by the mobile network, LTE can organizing the vehicular network in a set of clusters, in a centralized manner.

In support of VANET network, the wireless access standards are given in Table 3.1.

Several reasons claim the LTE and LTE-A applicability in vehicular environments:

- *Centralized architecture* The use of a centralized mechanism seems to be better than the use of a decentralized mechanism, since an eNodeB has a global view of its coverage area and can thus improve the management and maintenance of the clusters.

- *Capacity* LTE offers high downlink and uplink capacity (up to 300 and 75 Mbps, respectively, in Rel. 8, and up to 1 Gbps for LTE-A in Rel. 11) that potentially supports several vehicles per cell. Such values are higher than 802.11p, which offers a data rate up to 27 Mbps.

- *Coverage and Mobility* LTE will rely on a capillary deployment of

Table 3.1: Comparison of some wireless access standards.

Feature	**802.11p**	**LTE**	**LTE-A**
Channel width	10 MHz	1.4, 3, 5, 10, 15, 20 MHz	Up to 100 MHz
Frequency band(s)	5.86-5.92 GHz	700-2690 MHz	450 MHz-4.99 GHz
Bit rate	3-27 Mbps	Up to 300 Mbps	Up to 1 Gbps
Range	Up to 1 km	Up to 30 km	Up to 30 km
Capacity	Medium	High	Very High
Coverage	Intermittent	Ubiquitous	Ubiquitous
Mobility support	Medium	Very high (up to 350 km/h)	Very high (up to 350 km/h)
Broadcast / Multicast support	Native broadcast	Through eMBMS	Through eMBMS
V2I support	Yes	Yes	Yes
V2V support	Native (*ad hoc*)	No	Potentially, through M2M
Market penetration	Low	Potentially high	Potentially high

eNodeBs organized in a cellular network infrastructure offering wide area coverage.

- *Channels and transport modes* The downlink transport mode (unicast or broadcast) and the selected uplink/downlink transport channels have an effect on the delay and capacity in terms of maximum number of vehicles per cell.

3.1.3 Challenges

The nodes in a VANET network are constrained due to the following: limited communication bandwidth and capacity between nodes (vehicle), information security, communication overhead and highly dynamic topology.

Due to the limited capacity of the communication medium, wireless networks suffer from bandwidth problems. This restricts the amount of information to be transmitted over a particular time duration. Efficient and innovative transmission techniques need to be invented to utilize the available bandwidth effectively and to increase the capacity. The use of efficient transmission techniques and the structure of cellular communication mechanisms are very helpful in effectively using the available capacity. However, there is still the need of more research in this area to provide more efficient mechanisms for better utilization of the available communication bandwidth in the wireless communication environment.

Due to less security of the wireless communication medium, ad hoc wireless networks are more prone to security threats than their wired counterparts. Achieving the desired information security level requires additional processing overhead, which will be a major problem for the mobile nodes due to their limited processing power. It also requires additional bandwidth for secured transmission. A significant amount of research is already going on for discovering mechanisms for ensuring secure information transfer while at the same time not being prohibitive in terms of overhead. Major security requirements for a VANET are: authentication, message integrity, entity authentication, access control, privacy (location privacy is also important), real-time guarantees. This can be built into protocols to ensure that the time sensitivity of safety-related applications such as collision avoidance is met.

Due to the limited capacity of the wireless medium, minimizing the communication overhead for information transfer in ad hoc wireless networks has become one of the biggest and most formidable challenges. In order to ensure proper delivery of information, a path needs to be established between the source and the destination. Moreover, a procedure that will ensure the sharing of a common pool of resources, such as bandwidth, has to be established. One of the biggest challenges for designing routing protocols for mobile ad hoc networks is to handle the highly dynamic topology of these networks. For a source node to send information to a destination node, the source must be able to find the location of the destination node as well as other intermediate nodes. But due to their highly dynamic nature, the mobile devices change their locations frequently. As a result, a route that is established at the initial phase of the information transfer between two mobile devices may not be the same at the later phase of the information exchange. In order to adapt to this highly dynamic scenario, the routing protocols must be dynamic and adaptive in nature and the nodes must maintain up-to-date routing information all the time.

The routing protocols for mobile ad hoc networks are basically of two types: proactive and reactive. In the case of a proactive approach, the nodes need to maintain up-to-date routing information to all the nodes all the time. This requires the nodes to exchange the routing information between them periodically. The advantage of this approach is that the devices will always have routes available to other devices. Timely and periodic exchange of routing information will ensure the availability of fresh routes. Moreover, due to the immediate availability of the routes, no time will be wasted in setting up the path between the source and the destination devices. This ultimately reduces the delivery time of the information from the source to the destination device. The disadvantage of the proactive approach is the high overhead due to the periodic exchange of routing information between all the devices, even when all the routes may not be required.

In the case of a reactive approach, the routes to the destination are determined on an on-demand basis. The advantage of this approach is that the overhead incurred will be reduced as only the routes that are needed will be discovered. There is no need of periodic information exchange between the devices. However, this approach will suffer from more waiting time because routes will not be immediately available. The initial path setup takes a significant amount of time and, during this time, no packet can be sent to the destination due to the unavailability of routes. In order to combine the advantages of these approaches, many hybrid routing mechanisms have been introduced. However, the problem of finding the shortest routes with minimum overhead remains an open challenge.

With LTE Release 9, a few enhancements were added to the previous release LTE such as support for broadcast and multicast services (E-MBMS), defining new self-optimization features for self-organizing network (SON) capabilities, etc. SON functions can be divided into two categories: self-configuration and self-optimization.

The major challenges in securing VANETs are outlined: tradeoff between authentication and privacy, high mobility, scale of network, real-time guarantees, incentives, location awareness.

Also question is what type of adversaries would target the system and type of attacks they are capable of launching against the system as: selfish drivers, eavesdroppers, teenage hackers, insiders, malicious attackers. VANETs are susceptible to various types of attacks: denial of service, impersonation, message falsification, message alteration, message delay and suppression, privacy violation, replay attacks, hardware tampering, sensors tampering, high processing power and adequate power supply, known time and position, limited physical access, periodic maintenance and inspection, central registration: Another advantage of the VANETs is that, unlike other ad hoc networks, honest majority, existing law enforcement infrastructure.

Safety applications require periodic V2V data exchanges in a vehicle's neighborhood (this is the case of CAMs) or event-triggered V2V and V2I communications (this is the case of DENMs). CAM and DENM exchanges in LTE involve transmissions from vehicles to infrastructure nodes, and successive traffic distribution to the concerned vehicles. Analytical results show that LTE is unable to satisfy the CAM delivery requirements when the eNodeB retransmits all received CAMs to every vehicle in the cell in unicast mode.

Similar results are achieved when the eNodeB unicasts CAMs to every vehicle in the one-hop neighborhood. Improvements can be obtained through CAM broadcasting in the cell. DENMs generate a lower traffic load compared to CAMs; thus, the cell capacity is only temporarily and partially used.

- A hybrid network architecture composed of two systems: a clustered VANET network and an LTE- advanced infrastructure under the context of evaluating the impact of VANET integration into cellular systems. In a clustered topology, the CH is usually set as the default gateway to the infrastructure for all source vehicles of the cluster. The key advantage is to decrease the cellular network resource consumption by multiplexing distinct source node flows into one gateway that handles sending them to the infrastructure. However, this method causing CH overload, increasing end-to-end delay as compared to the direct link (that is sending directly to the eNodeB) which is intolerable for delay-sensitive services. Moreover, there is no proposed algorithm for gateway selection to infrastructure that considers traffic priority as a criterion. Q: How to make decision for appropriate gateway to connect a source vehicle to the LTE-A network.
- The very dynamic network topology due to vehicles high velocity, aiming to ensure acceptable V2V and V2I communications. Most of the solutions proposed for handling these issues are based on the creation of dynamic clusters to self-organize the IEEE 802.11p vehicular network. Clustering in VANET aims to organize vehicles into groups based on some specific common characteristics. Q: How to choose appropriate the cluster head (CH) and how to mitigate CH overload.
- The main challenge is related to simultaneous warning transmission attempts by all vehicles detecting a specific hazard. Then backend server plays the crucial roles of reflector and aggregator. It can filter the multiple uplink notifications of the event according to the location, time stamp, and heading field of the received messages, and send out only one consolidated message. This latter feature allows the server to infer a better global view of the road conditions. Such an added remote intelligence, which tracks events, can only be offered in a centralized architecture.
- The design of efficient schedulers is especially crucial for the uplink channel that could be a bottleneck in densely populated networks. On the downlink, instead, the effort is to provide efficient and reliable broadcasting that coexists with conventional unicast mode (packet scheduling and QoS support.

3.1.4 Actions

- Investigating the complementary roles of IEEE 802.11p and LTE in supporting cooperative ITS applications.

- The research focused on the design of LTE packet schedulers that satisfy the often conflicting objectives of high spectrum efficiency, throughput, and fairness.

- An efficient gateway selection algorithm (CH) is one that considers QoS features of traffic to be transmitted to the infrastructure (VANET-LTE-A).

- Clustering in VANET aims to organize vehicles into groups based on some specific common characteristics. Therefore, it is important to propose a method that considers traffic priority and sensitivity on one side and becomes aware of VANET and infrastructure features on the other side.

- Due to this highly dynamic scenario, routing is considered a challenging task in vehicular ad hoc networks. Hence, the design of efficient routing protocols to suit the needs of VANET networks has become a key issue

- For implementing VANET security, it is essential to understand the unique challenges: tradeoff between authentication and privacy, high mobility, scale of network, real-time guarantees, incentives, location awareness.

- Further investigation is required to analyze: the reciprocal interference between CAMs and other traffic types, the effect of the LTE QoS class selected to carry CAMs, and the effectiveness of scheduling techniques deployed at eNodeB.

Chapter 4

Mobile Technologies for Autonomic Traffic Management

Contribution by: Apostolos Kotsialos, Durham University, School of Engineering and Computing Sciences, Durham, United Kingdom.

4.1 Mobile Technologies for Autonomic Traffic Management

4.1.1 Introduction

The emergence of hand-held devices in the form of smart phones, tablets or dedicated vehicle on-board devices, able to run a wide range of applications, has opened the gate for a new type of traffic control measures and possible implementations of traffic management systems. The information storage and delivery capacity from advanced human-machine interfaces provides the potential for a new era of traffic management. Although the technology of ubiquitous computing, V2V and V2I communications systems has been available for many years now and is relatively robust, the potential it provides for traffic control applications has not been sufficiently explored.

The dominant paradigm of traffic control measure applications is that of generating a signal affecting drivers' behavior at a certain area in an impersonal manner. This character of impersonality is due to the means of delivery used for this type of signals, e.g. the green phase of a traffic light or the diversion route advise given by a variable message sign to the incoming flow into a bifurcation. Although there is an individual response, the control signal is not individualised to the driver/vehicle level of the traffic system.

Hence, there is a fundamental imbalance in the generation and the application of the traffic signal. It is generated at a higher level of aggregation than it is applied at. Mobile and networking technologies provide the opportunity of individualised traffic control signal generation based on driver needs but also on system-wide considerations as well. In other words, traffic control can take place at the driver/vehicle system level significantly reducing the intervention executed at the network operator level.

Thus, the use of devices that are able to personalise their results based on the availability of large databases and information extracted in real time based on the extensive use of robust communications networks opens a new horizon of possible traffic applications at the traffic-operations level and the institutional as well. Autonomic computing provides the potential of supporting this change on the way traffic control is applied in different ways. The role of autonomic communication systems becomes more important and the design of ITS applications based on mobile devices will need autonomic computing capabilities to support a variety of services to the driver and the road transport infrastructure.

4.1.2 State of the Art

Most of the relavent literature on the use of mobile devices for traffic management applications is concerned with various aspects of the traffic surveillance and prediction systems. These type of systems are concerned with one or more of the following problems.

- **Traffic state estimation.** This is about estimating the traffic state in terms of density, mean speed and volume over a road network. State estimation algorithms usually employ some version of Kalman filter estimation based on a variety of sources providing real time data. Typically, these data sources come from sensors placed at fixed point locations over the road network providing traffic information (counts, speeds, occupancy etc). Based on this local information, estimation algorithms aim at providing a more complete picture of the traffic conditions over the road network, in other words, to fill in the details the localised nature of the fixed position sensors are missing. Information based on mobile devices, such as GPS location coordinates of vehicles in conjunction with speed measurements sent over a variety of communication networks, is used improve the estimation algorithms' performance. By exploiting this more detailed level of personalised (even after anonymization) information better and more relevant estimates can be produced.

- **Traffic state prediction.** This is about predicting the future traffic state of the road network in terms of mean speed, vehicular volume and density over a future time horizon. There are two main approaches to this problem, model based and time-series based, with a large number of different subcases for each. Model-based approaches use the current traffic state estimate as initial state of a network-wide dynamic traffic flow model and in conjunction with disturbance predictions (traffic demand, OD matrix, routing behavior, weather conditions, incidents or other capacity reducing events)

predict the

4.1.3 Challenges

4.1.4 Actions for the community

Chapter 5

Motorway traffic control

Contribution by: Ioannis Papamichail, Dynamc Systems and Simulation Laboratory, Technical University of Crete, Chania, Greece.

5.1 Introduction

Motorways had been originally conceived to provide virtually unlimited mobility to road users. However, the continuous increase of vehicle-ownership and demand has led to the daily appearance and continuous increase (in space and time) of recurrent and non-recurrent motorway congestion, particularly within and around metropolitan areas. Ironically, daily recurrent congestion degrades the available expensive motorway infrastructure by reducing the nominal infrastructure capacity at the peak period, i.e. at the only time this capacity is actually needed, causing excessive delays, increasing fuel consumption and environmental pollution, and reducing traffic safety.

The efficient, safe, and less polluting transportation of persons and goods on motorways calls for an optimal utilisation of the available infrastructure via suitable application of a variety of traffic control measures such as ramp metering, driver information, route guidance, variable speed limits, and further link control measures.

The recent developments and advances in the areas of computing and communications may support this effort, but it is evident that the ultimate efficiency of motorway traffic control depends on the efficiency and relevance of the employed control methodologies. Successful design of efficiency-increasing motorway traffic control strategies for a variety of available traffic control actuators calls for:

- good understanding of the motorway traffic flow behaviour with all related goals, subtleties and constraints;
- knowledge and application experience on the broad range of control design methods and approaches offered by control engineering.

As the complexity of large-scale traffic control systems grows, the need to build into them the means to manage and maintain themselves becomes necessary. Systems need to be self-directing, self-configuring, self-maintaining, self-protecting and self-optimising. One consequence of self-managing systems is that their interaction with people is set more at a "service" level than a "command" level. As a result, a traffic control centre manager will interface with future autonomic traffic control systems by communicating goals, priorities and tasks which the systems will solve.

5.2 State of the Art

As mention already, prevention or reduction of traffic congestion on motorway networks may dramatically improve the efficiency of the infrastructure in terms of throughput. Therefore, an increasingly important area in the field of traffic engineering is motorway traffic control (Papamichail et al., 2007). Various traffic control measures have been proposed and partly implemented in motorway networks to alleviate traffic congestion:

- Ramp metering, the most direct and efficient way to control motorway networks, is potentially valuable but its positive effect may be limited due to limited ramp storage space (Papamichail et al., 2010a).
- Mainstream traffic flow control (Carlson et al., 2010) mainly applied using variable speed limits as actuators.
- Route guidance and driver information systems are most helpful under non-recurrent, e.g. incident- induced, congestion (Wang et al., 2006).
- Emerging vehicle-infrastructure integration (VII) systems provide a promising technological background for efficient traffic control, but specific efficiency-improving applications and corresponding control algorithms are still to be developed.

Integration of various control measures into a single hierarchical system could of course be proven more beneficial. Autonomic systems can be viewed as multi-layered hierarchical systems facilitating the operations necessary for achieving a general policy goal respecting at the same time constraints and regulations. A more detailed review is presented in the following sub-sections for motorway control via ramp metering and mainstream traffic flow control. A self-adaptation algorithm that has been used for traffic control problem is presented next.

Ramp metering

Ramp metering aims at improving the motorway traffic conditions, by appropriately regulating the inflow from the on-ramps to the motorway mainstream. Ramp metering strategies can be classified as fixed-time or traffic-responsive. Fixed-time strategies are derived off-line for particular times of the day, based on historical demands. Due to the absence of real-time measurements, they may lead either to overload of the mainstream flow (congestion) or to underutilization of the motorway. Traffic-responsive ramp metering strategies are based on real-time measurements from sensors installed in the motorway network and the on-ramps and can be further classified as local or coordinated.

Local ramp metering strategies make use of measurements from the vicinity of a single ramp and include feed-forward control approaches, such as the demand-capacity strategy and its variations, feedback control approaches, such as the ALINEA strategy and its, as well as neural network or fuzzy-logic based approaches. On the other hand, coordinated ramp metering strategies make use of measurements from an entire region of the network to control all metered ramps included therein. Coordinated strategies may be more efficient than local ramp metering strategies when there are multiple bottlenecks on the motorway or restricted ramp storage spaces. Coordinated ramp metering approaches include multivariable control and optimal control strategies. A detailed overview is given by Papamichail et al. (2010a).

Multivariable regulators are derived from linearization of the strongly nonlinear traffic flow models, which limits their efficiency in case of heavy congestion. On the other hand, optimal control approaches employ relatively complex numerical solution algorithms that may be a burden for field application. This may be the main reason why field-implemented coordinated ramp metering strategies up to now have been based on heuristic rule-based approaches. Bogenberger and May (1999) presented an extensive review of heuristic coordinated traffic-responsive ramp metering algorithms. A number of studies have compared the performances of these algorithms. Recently, these comparisons were summarized by Hadi (2005) for a number of heuristic coordinated strategies that have been implemented in USA, including the Zone and the Stratified Zone algorithms, the Bottleneck algorithm and the Helper algorithm.

HERO, a new heuristic traffic-responsive feedback control strategy that coordinates local ramp metering actions in motorway networks was recently developed. HERO was extensively tested via simulation (Papageorgiou et al. 2006; Papamichail and Papageorgiou 2008) as well as in field implementations (Papamichail et al. 2010b; Faulkner at al., 2014). The proposed coordination scheme is simple and utterly reactive, i.e., based on readily available real-time measurements, without the need for real-time model calculations or external disturbance prediction. HERO has a modular structure and includes many interacting and cooperating feedback control loops (e.g. mainstream occupancy control, ramp queue- length control, waiting time control) and two Kalman Filters for the estimation of the ramp queue-length and the mainstream critical occupancy. Generic software has been developed that implements the HERO coordination scheme for any motorway network via suitable input configuration.

Mainstream traffic flow control

Mainstream traffic flow control (MTFC) is a novel control measure (that may complement existing ones) aiming at directly influencing the motorway mainstream flow via an appropriate actuator such as: variable speed limits (selected from an enlarged range of values) or specially operated traffic lights or emerging VII systems. The basic idea of MTFC may be traced back to some articles of the 1980's and 1990's. Mainstream traffic flow control has been considered to some extent in some recent works under different approaches and traffic application settings. A detailed review has been presented by Carlson et al., 2010. This paper presented also the application of an integrated optimal control (ramp metering and variable speed limits) approach to a simulated large-scale motorway ring-road to investigate the operational impact and potential benefits of MTFC under realistic conditions. In a more recent work, Carlson et al. (2011) presented a local feedback-based mainstream traffic flow controller utilising variable speed limits.

An adaptive fine-tuning algorithm

Due to the complexity and the strong nonlinearities involved in the modelling of traffic flow processes, the design and deployment of efficient large-scale traffic control systems remains a significant objective. Practical control design approaches are often based on simplified models for the system dynamics, as the use of more complex models is virtually infeasible in most real life applications. As a result, although the derived regulators may be theoretically optimal, they usually exhibit suboptimal performance. The ultimate performance of a designed or operational traffic control system (e.g. ramp metering or variable speed limit) depends on two main factors: (a) the exogenous influences, e.g. demand, weather conditions, incidents; and (b) the values of some design parameters included in the control strategy.

Every time a new control algorithm is implemented in the real world, there is a period of (sometimes tedious) fine- tuning activity that is needed in order to elevate the control algorithm to its best achievable performance. Fine-tuning concerns the selection of appropriate (or even optimal) values for a number of design parameters included in the control strategy. Typically, this procedure is conducted manually, via trial-and-error, relying on expertise and human judgment, without the use of a systematic approach. Currently, a considerable amount of human effort and time is spent by experienced engineers, practitioners and traffic operators on tuning operational systems. In many cases, the result of this manual procedure does not lead to a desirable outcome in terms of a measurable performance metric.

AFT (Adaptive Fine-Tuning) is a recently developed algorithm (Kosmatopoulos et al., 2007; Kosmatopoulos, 2008) that combines the principles of traffic engineering, automatic control, optimization and machine learning and enables online self-tuning autonomicity for operational traffic systems. This online procedure is aiming at replacing the conventional manual optimization practice by embedding self-tuning capabilities in control strategies. AFT can self-adjust the tunable parameters of control systems, so that they reach the maximum (measurable) performance that is achievable with the utilized control strategy. The method can also be used for automatic re-adjustment of "aged" systems.

Given the positive feedback from the simulation investigations for different control problems (including ramp metering, variable speed limits as well as urban signal control, see Kosmatopoulos et al. 2008a; 2008b; Kouvelas et al. 2011), the algorithm was implemented in the field for the urban traffic control of Chania, Greece. Some preliminary results have been recently presented by Kouvelas et al. (2013). The results demonstrated the applicability of the algorithm and its efficiency in solving the tuning problem of real life operational control systems. AFT will also be used in the field coupled to a variable speed limit algorithm in the frame of the ERC Advanced Investigator Grant TRAMAN21 (www.traman21.tuc.gr).

5.3 Challenges and Actions

Some isolated examples of autonomic properties, such as self-adaptation, self-configuration and self- healing, have found their way into RTS technology, and have already proved beneficial in field applications (Papamichail et al., 2010; Kouvelas et al., 2013).

A first step towards developing autonomic systems, that achieve higher policy goals, is the introduction of a common vocabulary able to articulate and capture the requirements of network operators needs. Naturally, such a vocabulary is already in existence in operating Traffic Control Centres, out of necessity, if anything else. This practical knowledge and natural language of operations needs to be captured and explicitly developed in such a way so as to facilitate the automatic capturing of policy requirements. Such a system would allow operators to define and articulate policies in a simple and intuitive way from the human perspective, but with sufficient content of information, for allowing the automatic organisation and execution of all the small and lower level actions, from the application systems perspective. The automatic capturing of policy requirements and the mapping into specific actions at different levels disaggregating the higher policy objective into lower level execution commands is a vital step for the development of autonomic traffic control applications. This kind of system development needs to be performed for both the network operator and the vehicle/driver system.

Although the traffic control measures presented in the state of the art section (as well as their integration) are fairly mature from a theoretical point of view, the immediate implementation of their majority remains a difficult task since it requires the implementation of other applications supporting them, e.g. an origin- destination module, a demand prediction module, a state estimation module, an incident detection module and so forth. All these applications span over multiple levels of system hierarchy and are based on multiple overlapping and cascading control loops. It is for this coordination and organisation effort integrating all these applications where autonomic system design can deliver viable systems that are functional for network operators. Identifying the control loops that need to be endowed with self-* properties is the first step for the successful deployment of autonomic traffic control systems.

Chapter 6

The Autonomic Traffic Management Paradigm and its Multilevel Formalization

Contribution by: Todor Stoilov, Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Sofia, Bulgaria.

6.1 Introduction

The information technologies (IT) has significant progress nowadays. This fact together with development of Internet leads to propagation of information and communication technologies in nearly all areas of life. However, the information technologies require competent influence of IT specialists. As the variety of proposed information services increase very fast, the IT specialists can not maintenance these IT services and their interaction which leads to impossibility for servicing all these systems, computers, communications and customers. The IT and their wide propagated spectrum stay behind the maintenance of IT specialists. In the near future as the technologies development and their variety has higher speed than their maintenance, a shortage of corresponding IT specialists is expected and the system "customer- services" will not be able to work. To overcome this negative tendency Paul Horn, vice-president of IBM alarmed the scientific society in 2001 and proposed the scientists directions for thinking and research. His idea is based on creation of new opportunities for decision making and essential calculation and communication operations without human participation, i.e. development of automatic systems. The efforts have to be directed to development of computer systems, which are self-controlled at the same manner like the humans nervous system-it regulates and protect our body. These systems are known like autonomic computing systems. Today, existing technologies allow particular realization of self-controlling approach concerning separate components. For instance, IBM proposes products with some of the opportunities of self-controlling systems. Some of them are based on self-configuring, self-healing, self- optimization or self-protecting technologies (www-3.ibm.com).

The goal is to be developed and realized self-controlling systems which have possibilities for adaptation to the existing changeable conditions and can allocate effectively their resources. In that manner higher productivity will be realized and at the same time the complexity for the customer will be less.

6.2 State of the Art

The following 8 characteristics of autonomic computing systems are given by IBM [4, 13]:

1. The autonomic computing systems have to know themselves - their components have to present the system's identity. As the system can exist on many layers, it is necessary detailed knowledge of the state of all its components, their capacity, final states, and relations to other systems in order to be controlled. The system has to know the available resources, these, which can borrow or give away to other systems and also these resources which can not give away (they have to be isolated).

2. The autonomic computing systems must change their structure in some conditions and self- configured. This pre-structuring has to become automatically by dynamical adaptation to the changing environment.

3. The autonomic computing systems have to optimize their work. They have to observe their consisting elements and the tuning working flow in order to reach the preliminary put goals.

4. The autonomic computing systems have to be able to self-heal themselves from usual or unusual events which can damage some system's elements. They have to find problems or potential problems and to discover alternative ways for using resources or to reconstruct the system in order to keep its normal functioning.

5. The autonomic computing systems have to be able to protect themselves. They have to find, identify and protect from different kinds of attacks, to maintain the safety and entity of the system.

6. The autonomic computing system has to know its environment and to act according it. It has to find and generate rules how to interact with the neighbour systems. It has to use the most appropriate resources

and if they are not available to negotiate with other systems in order to take them from these systems. In this process it has to change itself and the environment or it has to be able to adapt itself.

7. The autonomic computing systems cannot exist in closed environment. They have to act in various environments and to apply open standards. In that manner, the autonomic computing systems do not perform preliminary done decisions. They have to continuously make decisions.

8. The autonomic computing system has to predict the necessary optimal resources for accomplishing the current tasks. The system has to satisfy quality of services and it has to arrange the information-technological resources in a manner to decrease the distance between the business and personal goals of the customer and the IT instruments.

IBM stresses on four aspects of self-controlling, summarized in Table 6.1 [5, 7].

The way which has to pass while autonomic computing systems can be developed is quite long and several important steps regarding the self-control are proposed in [5]. In the beginning the automatic functions are related to collecting and aggregating the information needed for decision making by administrators. Later, they will serve the system like advisors proposing possible directions for working, which people have to have in mind and to make decisions. As the technologies for automation are improved, it is expected the autonomic computing systems to make decisions on lower level. Later, the people will rarely make decisions at high level because the system automatically after numerical calculations at lower level will make decisions. This process will continue until the systems administrators will not have any essential work because it will be done by the system.

6.3 Challenges

University research projects in autonomic computing

Berkeley University of California developed a large data storage system in OceanStore project [3]. The system satisfies self-configuration, self-optimization, self-protection and self-healing for its management components. The system maintains a strategy computing everywhere and connectivity everywhere in its operation. The system has the following features: autonomic maintenance, adaptation in routing decisions and finding data locations, conflict resolution on encrypted data, autonomic replication and archival storage, optimization and self-repairing.

Oceano project is related to multi-customer hosting over a virtualized collection of hardware resources (IBM Research). The computing utility infrastructure consists of a set of massively parallel densely-packed servers, interconnected by high-speed switched LANS. The computer farm is managed, supporting self- optimization, component monitoring, autonomic resource distribution under user demands.

Q-Fabric system supports continuous on-line quality management [9]. The system monitors and controls the use of resources, reacting to dynamic changes in user requirements, to resource availabilities, to system anomalies for efficient resource utilization. The Q-Fabric system has self-organization features for on-line management and on-line optimization for quality of user services.

Automated taxonomy generator Sabio is presented in [10]. Sabio is a program analysing thousands of documents and creating taxonomy for the entire collection. Sabio applies properties as self-organization and self-management.

The above projects are only a small part of the numerous initiatives, developed on this topic. The autonomic computing principles will be applied widely in different engineering applications and technological domains: control systems in industrial automation and process control, autonomic manufacturing processes; information processes for load balancing, spam detection, secure data protection; traffic systems and transportation behaviour.

Autonomic behaviour for transportation systems

The autonomic behavior for the transportation systems is inspired mainly from the complex nature of the traffic phenomena and the necessity to resolve the associated decision making problems by the road operators.

The complexity of the traffic management comes from the requirements to solve a set of management traffic tasks and the technical devices and systems, which can provide parts of the needed functionality of the traffic control system. The basic structure of a road control system is equipped with sets of sensors of different types, which have to make measurements, needed for the traffic management. Additionally, the traffic processes are subjected to a number of noisy inputs like weather conditions, subjective driver decisions, incidents which cannot be predicted neither controlled in the traffic management system. Thus, the traffic management is strongly influenced by a human traffic manager, who decides how to manage the traffic according to his competence about the traffic needs.

The traffic operators receive a lot of information from various set of resources and thus they are suffering from information overload. To solve efficiently the traffic problem, the traffic management cannot rely only on the experience of the human operators. A general description of the management functionalities of traffic management system can be presented in the following Figure. Such a system targets the implementation of traffic control loop and integrates different subsystems, resolving local control tasks.

Figure: Traffic control loop

A prospective way to tackle the complexity of the problem for traffic management is to apply the concept for the autonomic behaviour of several local control subsystems and to coordinate their functionalities in a multilevel control system. Because the traffic management system is a distributed system with local subsystems, each operating with its own goal and functionality, the challenge is to provide self-* properties to each subsystem and to create a cohesive management policy that will integrate the subsystem capabilities taking into account the subsystems interactions. This will allow the control policies and local control influences to adapt the overall traffic control accordingly.

Coordination and self-management systems

The traffic control system represents complex system in which the complexity is related not only to its dimension (large scale systems) but to the influences among the different parts of the system as well. It is typical complex system consisting of many subsystems, interaction each other.

The large scale systems are usually nonlinear and because of the dynamical nature of the control processes arises a need for development of new methods. The classical case is centralized manner of data acquisition, which is not suitable for complex and distributed systems because of the large scale control problems which have to be resolved for limited time period. Respectively, the technological control devices have to satisfy the increased requirements in real time. The implementation of such control devices is impossible, very difficult, or inefficient for real time applications [6,8, 11].

To overcome these problems hierarchical multilevel systems can be recommended. They develop and apply decomposition approaches for independently operating local subsystems. The multilevel hierarchical systems theory has formalization which is more general than mathematical programming. This formalization of hierarchically operating subsystems and their coordination is a set of solutions of hierarchically ordered optimization problems. Unfortunately, the multilevel optimization does not have a lot of real-time applications. The main reason is that the advantage of multilevel programming for representing the decision-making processes is hardly to achieve because of the complex iterative algorithms [5]. However, the multilevel optimization allows to be ordered and consciously linked a sequence of operation, resulting in self-organizing systems: control, optimization, adaptation self- organization, (see Figure).

This hierarchical order allows application in formalization of autonomic computer systems. The general system operation is presented as a process of solution of hierarchically interconnected optimization problems, formulated as [12]

$$\begin{array}{l} \text{Problem P1} \\ \min\limits_{x^k} f_k\left(x^1, x^2, \ldots, x^k\right) \\ \text{subject to} \\ g_k\left(x^1, x^2, \ldots, x^k\right) \leq 0 \end{array}$$

where x^1 solves

Problem P2

$$\min_{x^1} f_1\left(x^1, x^2, \ldots, x^k\right)$$

subject to

$$g_1\left(x^1, x^2, \ldots, x^k\right) \leq 0$$

Problem P1 is solved by the coordinator, which is at the highest level of hierarchy. The decision maker (coordinator) at this level controls the decision variables and its objective is to minimize function. Similarly, (P2) is the first level problem and it corresponds to the lowest level of hierarchy. The multilevel optimization problem P1 is hard to be solved [1,2]. Even in the simplest version of two level optimization it becomes non-convex and/or non-smooth and belongs to the class of global optimization [2].

The solution of the optimal design problems with non-smooth structure can be found by different manners - applying a penalty function method; Karush-Kuhn-Tucker type conditions; a pure non- differentiable optimization technique (bundle optimization algorithm). Taking into account the dynamical behaviour of autonomic systems, the above approaches of solving hierarchically optimization problems are not appropriate.

A potential solution for the coordination strategy is so called “non-iterative” coordination [12]. The local subsystems solve and send to the coordinator their suggestions $x(0)$, evaluated with lack of coordination (each subsystem is working independently for achieving its local goal). The coordinator, having these “suggestions” modifies $x(0)$ towards the global optimal solution , which concerns the compromise of mutual operation in the framework of overall system. Then, these corrections are transmitted to the subsystems for implementation. For two level hierarchical systems the iterative data transfer between the levels is reduced to only two communications, Figure **??**. The non-iterative coordination has been developed for the both main coordination strategies - goal and predictive coordination.

Figure: Two level hierarchical system

The coordinator influences the goal functions of the subsystems for goal coordination. For the case of model prediction, the coordinator influences the resources, which each subsystem uses for its operation. This coordination strategy has application in different areas like financial resource allocation [12]. The formal models of the non-iterative coordination founds on approximation of inexplicitly given dual Lagrange problems and corresponding inexplicitly given extreme functions [12]. By solving sequentially optimization problem an autonomic computing system can be managed in a way in accordance with environmental changes, mainly for the workload of the system and respecting the individual independency of each control subsystem.

The multilevel hierarchical system is an attempt for traffic control management modelling where the different traffic flows are the subsystems of the multilevel system. Each traffic flow (subsystem) has in some degree relation with others. The constraints of the subsystems' problems reflect the different kinds of resources which have to be respected (weather, traffic jam, incidents, etc.). The goal of the whole traffic flow system is minimization of conjunctions of traffic light crossroads.

The next research steps concern integration of different control loops in hierarchy and identification of appropriate levels for autonomic behaviour. The set of potential subsystems, which can perform the autonomic functionality, can be:

1. Knowledge based systems for road traffic management. They have to integrate heterogeneous knowledge and tools able to represent the direct requirements for traffic behaviour, based on current acquired knowledge, and semantic technologies. This knowledge can influence the set points and the behaviour of autonomic elements of the traffic management system.

2. Application of advanced technologies for traffic management. Technological advances in the field of computer and communication networks, mobile devices, application of web- services give the background for new solutions of traffic management problems. This is a potential for implementation of information technology solutions for traffic management purposes.

3. Autonomic traffic surveillance systems. The traffic monitoring and surveillance targets the real time assessment of the traffic network status as prediction of future traffic behaviour. The tasks, which have to be resolved, are data collections from traffic sensors, information processing in real time, implementation of set of information services and forecasts of system's behaviour (detection of incidences, demand predictions, traffic flow dynamic changes).

4. Autonomic real time traffic control systems. The traffic control is a target for the overall system. The control influences have to be evaluated and implemented for signal control, ramp metering, route guidance, variable speed limits calculations. The autonomic traffic control has to lead the traffic behaviour to a desire state by means to overcome congestions. The autonomic paradigm will rise new control problem formulation and respectively their solution and control implementation.

5. Autonomic demand management systems. Traffic demand has to be controlled on different time base: short term and long term management. The autonomic control has to identify the traffic changes and to provide in real time information, influencing the driver behaviour in choosing the right travel route.

6. Autonomic logistics operations. The autonomic logistic applications can increase the commercial transportation of goods. This is related to booking of transport services, estimation of arrival time of goods, assessment of loading schedules.

These different application topics for the implementation of the autonomic paradigm in transport control and transportation systems are strongly interconnected. They can be incorporated in a common hierarchical control system, which will operate for the overall transport system in an efficient way, with lack of active human intervention.

6.4 Actions

The challenge of developing autonomic computing systems rises searching of quantitative formal models, describing their behaviour and dynamical management. One approach for modelling and management of independent operating subsystems is by multilevel hierarchical system theory. The coordination strategies achieve optimal control and system management. The non-iterative coordination, developed for on-line application of multilevel systems concept, is a tool which allows performing on-line adaptation towards the system's behaviour changes.

This research suggests for the future traffic management the implementation of the autonomic paradigm. One possible way for implementation of this new control policy could be the usage of hierarchical system management which has strong potential to respond to the requirements of autonomic system design, applied to transportation systems.

Table 6.1: Four aspects of self-controlling today and later [5, 7].

Concept	**Current computing**	**Autonomic computing**
Self-configuration	Corporate data centers have multiple vendors and platforms. Installing, configuring, and integrating systems are time consuming and error prone.	Automated configuration of components and systems follows high-level policies. Rest of system adjusts automatically and seamlessly.
Self-optimization	Systems have hundreds of manually set, nonlinear tuning parameters, and their number increases with each release.	Components and systems continually seek opportunities to improve their own performance and efficiency.
Self-healing	Problem determination in large, complex systems can take a team of programmers weeks.	System automatically detects, diagnoses, and repairs localized software and hardware problems.
Self-protection	Detection of and recovery from attacks and cascading failures is manual.	System automatically defends against malicious attacks or cascading failures. It uses early warning to anticipate and prevent system wide failures.

Chapter 7

Junction control

Contribution by: Kenneth Scerri, Faculty of Engineering, University of Malta, Msida, Malta.

7.1 Centralized Junction Control

7.1.1 Introduction

Modern urban areas are witnessing increasing traffic congestion due to high car ownership rates and a strong dependency on private cars. Junctions often pose the main bottleneck in the urban traffic network resulting in capacity flow on the network links and excessive delays. A continuous expansion of the infrastructure cannot remain the go-to solution to these problems due to environmental and financial limitations. An alternative is the use of dynamic traffic control strategies that are adaptable to prevailing traffic conditions. Such methods can prove a safe and feasible solution to traffic congestion problems through the efficient and intelligent use of the network.

7.1.2 State of the Art

Various types of centralized adaptive control systems are already commercially available and have shown promising results. Two such widely used systems are SCOOT[1] and SCATS[2]. These systems use real time measurements to dynamically effect the split time, offsets and cycle time according to current traffic conditions. These commercially available systems are known to be very well optimized for under-saturated traffic conditions; however, their performance tends to deteriorate in heavy traffic[3]. Other widely used control systems including OPAC[4], PRODYN[5] and RHODES[6], implement model-based optimization and thus use current traffic measurements to identify in real-time an optimal control strategy.

From a research perspective, the last two decades also saw the introduction of the TUC system[7]. This system is based on the store-and-forward model as proposed by Gazis and Potts[8], where a multivariable linear regulator approach is used to optimize in real-time the network splits. The closed-form solution obtained makes this system ideal for real time implementation, however such an approach cannot handle constraints and hence requires a final tuning procedure. Nevertheless, TUC has been successfully implemented in various places including Greece[9]. More recently, Tettamani et al.[10] proposed a traffic control system based on model predictive control. Other computationally expensive numerical solutions have also been proposed in academic literature, including genetically tuned controllers[11].

7.1.3 Challenges

The commercial junction controllers currently available on the market can be considered as automatic closed-loop control systems with a low-level of adaptability and optimization. From a control engineering perspective, current systems adopt the optimal and predictive control strategies well studied in the 1960s and 1970s. Although such automatic control ideas, aiming to adapt junction parameters as a function of current and predicted traffic behavior, are a step towards a more intelligent system, they fall well short of the basic characteristics of an autonomic system.

Autonomic systems aim to provide a framework that allows the end-user to focus on high-level policies and decisions. This is achieved by hiding the complex low-level interactions and decisions involved in the every-day running of the system, through a high-level of computational intelligence and automation. This takes the form of a number of self-* properties such as self-configuration, self-optimization, self- management and self-healing, just to mention a few.

Transportation systems stand to benefit significantly from an autonomic transformation due to these self-* properties. A self-configuring system may centrally identify a globally best configuration for the network signaling with traffic flow optimized though its self-optimization property. Slow changes in traffic flow patterns can be accounted for through its self-management property while rapid changes due to unforeseen circumstances can be accommodated though its self-healing property.

Nevertheless, current intelligent transportation systems exhibit very few of these self-* properties. The optimized, model predictive and adaptive systems currently developed are mostly aimed at improving the flow at one or a few junctions with little or no consideration to the full network. Thus, although they exhibit some of the self-optimization properties attributed to an autonomic system, the level of optimization is geographically limited and thus benefits in the traffic flow at these locations may come at the expense of other areas in the network.

Thus, the development of an autonomic system for junction control requires the embedment of autonomic properties at all levels; from the control of a single traffic light, to the optimization of the flow on all links. The self-optimization properties currently developed on a few junctions have to be expanded to the full network, through complete network models, while at each step ensuring that all the important autonomic properties are ingrained in the system infrastructure.

7.1.4 Actions for Community

Based on the current state of the art and in view of a fully autonomic junction control systems, the following actions may be identified:

- Computationally efficient models describing the current state of the network in real-time are indispensable for the development of autonomic junction control. These models need to allow for efficient estimation of the time-varying nature of the network as well as provide efficient traffic prediction and network analysis based on current traffic conditions.

- The network infrastructure needs to be upgraded to allow for the implementation of an autonomic system. Such a systems requires both distributed and centralized computational power, as well as efficient communication among the nodes and to and from a centralized intelligent unit.

- Although the behavior of autonomic systems is well studied in computer intelligence, their behavior when applied to transportation systems is mostly untested. Thus extensive research and development is required to adapt these methodologies to autonomic transportation in an effort of identify any possible limitations and thus adapt the algorithms to transportation setting.

- The final validation of these developments needs to come from a number of test studies on networks of varying dimension and complexity to highlight the cost benefits of autonomic transportation.

7.1.5 Conclusions

The last few years have witnessed a significant development in the control of traffic at signaling junctions. Nevertheless, these developments still fall short of the possibilities envisaged through the adaptation of autonomic properties to transportations. Algorithmic, computational and infrastructural developments are all required for the implementation of these autonomic properties to transportation. Finally, these new developments must be validated on a number of test-studies on networks of different dimensions and complexity, to highlight their advantages and identify any possible limitations.

Chapter 8

Autonomic Control of Electric traffic

Contribution by: Iisakki Kosonen, Aalto University, Finland.

8.1 Introduction

The cause of most traffic related problems is that the traffic system is already too much autonomic and the most autonomic part of the present system is the human driver. The driver behavior is based on autonomic self-regulation according to the traffic rules (figure 1). The self-regulation process is guided by external controllers such as traffic signs and signals. However, currently there is no way of preventing the autonomic drivers from speeding or driving against the red signal. Also the traffic demand is autonomic since anyone can enter the system at anytime and therefore whenever the capacity is exceeded, the traffic jam takes place. The capacity breakdown in the traffic jams can last much longer than the original reason that caused it. The management of the supply side the present traffic control systems are also autonomic in the sense that they scattered to isolated systems which are not aware of the higher level policies.

The higher level policies are also scattered into various autonomic administrative silos representing the various aspect of traffic like the traffic safety, fluency, public transport services and environmental effects, land use and so on. On top of that the actions on the policy level are far from real-time management. The decision are made based on surveys, rather than on continuous real-time data acquisition. Hence there is no single voice expressing the prevailing policy at given time and place i.e. there is no leadership, just managing of the traffic. Autonomic computing is one way of improving the traffic management, but not the only one. Advances in the traffic control and sensory systems, driver support systems, communi-

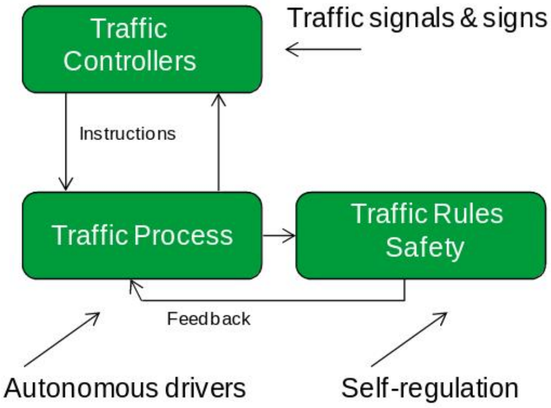

Figure 8.1: The traditional autonomic traffic management

cations systems (V2V, V2I, V2C, V2G) and vehicle moving power together with energy distribution systems will also help to build more sustainable road transport management. The important question with the autonomic computing is, how to provide flexible intelligence (the brains) to the future traffic management.

8.2 Autonomic traffic management

The autonomic computing could offer a framework of compiling the various (and sometimes contradicting) objectives into a consistent strategy and furthermore to implement the strategy into tactic and operational levels. The decision making need to take place in real-time time and based on the prevailing traffic situations. The autonomic computing should be used not only to top-down but also to bottom-up direction. The intelligence is not just making the right decisions, but it is also about making the right observations. The latter task is often undermined, even though major part of human brains are dedicated to autonomic processing the raw data from the ”sensors” into meaningful pictures in mind. In fact the human decision making capability is fairly limited given that the size of the working memory is approximately seven items.

No intelligent decisions can be made without situation awareness (figure 2), which is a model of the environment and its current state. In human mind the observing is not just passive analysis of the data received from the senses. The observing is based on existing models or prototypes, which are only complemented by the sensory data (for example everyone can see dreams or ”listen” the music without any sensory input). Another important aspect

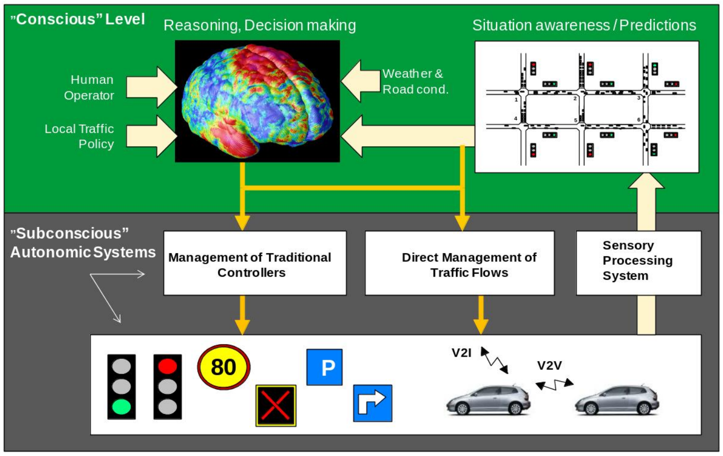

Figure 8.2: Autonomic Traffic Control Center

of human sensory processing system is that instead of just representing the current situation it tends to provide predictions which again are reflected as expectations as what is going to happen.

A similar approach could be used in the collecting and processing of the traffic data. All the existing knowledge of the traffic system could be compiled into a generalized computational representation (model), which is then complemented with the real-time input from the various sensors. Once the real-time model is operational it can also be used for short term predictions. The need for comprehensive and autonomic approach in the sensory processing system is necessary, since the rapidly increasing amount of various traffic sensors is going to explode the amount of available data in the near future.

The traffic management decisions in the field are made by autonomic agents, which are controlling the traffic on various levels. These control agents should self-organize into groups, in which they co-operate locally and which is leaded by a higher level management agent. The local management agents also group together with the same level of agents and the group is lead by metropolitan level control center. At any level the agent gets the objectives above and the situation awareness below its own level. It is important that all the agents within the same area and layer have the same awareness of the situation. Only this way the agents can appropriately negotiate about the optimal control strategy. This type of distributed architecture resembles the human administrative organizations, but it is operating in real-time. (figure 2 3)

For example a traffic signal controller is an agent, which has to be aware of the traffic situation in the junction and it has to be able to negotiate with its neighboring controllers to optimize the green wave. In the next level there is a local traffic control center, which provides local guidelines and objectives for the optimization, but leaves a certain level of autonomy to the controllers to work out the final solution. The area control centers again reports to the metropolitan level control center, which gives the guidelines based on the general traffic policy within whole city.

For the actual optimization of the traffic management there are number of algorithms which can be analytic, stochastic, adaptive, heuristic, learning, etc. The important factor is the capability of multi-criteria optimization. Instead of one optimal solution the algorithm provides a front or surface of optimal points, from which the final solution is selected based on the given policy.

8.3 Autonomic vehicles

Man has had fully autonomic vehicles since 4000 BC. This multi-purpose multi-fuel vehicle was equipped with hundreds of sensors, stereo vision, speech control etc. and it could maneuver through very difficult terrains without the drivers attention. It is clear the present cars are still far from the cognitive capabilities of the horse. The motorized vehicles provided more power and speed but the price was shifting more cognitive burden to the driver. The combination of high power, speed and mass with human control has turned out to be devastating. Tens of thousands people are killed and injured every year within Europe only.

The level of automation depends much on the mode of transport. Aviation, maritime, rail traffic is already highly automated and the autonomy is taken from pilots to the vehicles except the emergency situations. On the other end the light traffic like walking and cycling is not possible to be automated, so the ”driver” is still remains fully autonomic. The level of automation in the motorized road traffic is still very low, but it is possible to be increased significantly (figure 3).

Only recently the most advanced cars have been equipped with driver support systems, which help to keep in the lane, maintain car-following distance etc. Even fully autonomic vehicles have already been demonstrated, but there are still issues related technical reliability, legal aspects, road side infrastructure, harsh road/weather conditions and drivers attitude towards automated driving.

The important aspect is that the vehicle is becoming an active part of the autonomic traffic management. The car will become another autonomic agent capable of communicating directly with the driver, with the other vehicles and with the traffic control/management systems. With autonomic vehicle management it becomes possible to directly control both individual vehicles and the properties of the traffic flow.

For example the stopgo-type traffic signals control in junctions is inefficient causing a lot of unnecessary disturbance to the traffic. In autonomic traffic control the approaching vehicles are instructed to form dense platoons

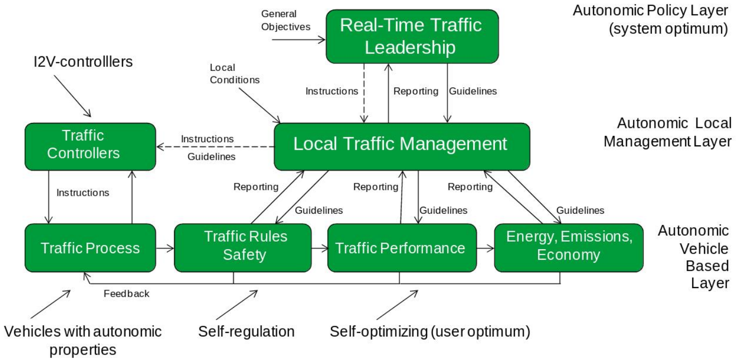

Figure 8.3: Real-time multi-criteria traffic management based on autonomic properties in vehicles

(road trains). The speeds of the successive platoons again are adjusted to create gaps between them for the conflicting traffic. The arrival times of the platoons into a junction are synchronized by smooth adjusting of speed of the leading vehicles. This way the capacity of the roads and junctions can be maximized and the speed changes and stops can be minimized together with the emissions and energy consumption. Similar approach applies of course to highway/motorway environment.

The local traffic control center would operate a bit similar to the flight control center by checking in and out the vehicles, forcing individual vehicles to join a platoons and smoothly adjusting the speeds and gaps of the platoons within its own area. The control center can also give general guidelines on what should be the car-following gap and the free speed within the controlled area. Vehicles and drivers still need to retain their own autonomy to react to any changes ahead to maintain the car-following gap, to avoid collision with any unpredictable obstacles like pedestrians for instance.

The development toward autonomic traffic/vehicle management can start gradually by making the driver support systems to communicate with the traffic control centers, but still keeping the man in the loop. The fully automated road traffic is still a bit futuristic view, but it is likely to start gradually from the highways towards more complicated urban street environments.

The future traffic management is going to be balancing between the human control, automation and autonomy. Human control is still prevailing, but the direction is towards more automation and less autonomy for the driver. The automated driver support systems can possibly compromise the human drivers ability to control the vehicle in unexpected situations.

There is also balancing between the user optimum and the system optimum. Assuming there is no higher level management, the drivers/vehicles will in autonomic way negotiate their route through the network seeking for their own user optimum. With fully automatized central control it is most likely get closest to the system optimum. With the policy driven central control together with some level of autonomy in the local control and vehicle control, it is possible work out a balance between the user/system optimum.

The autonomic and automated traffic management can bring lot of benefits especially from safety aspect. However, this is true only if the security aspect is very carefully arranged. The autonomic traffic management system could be most attractive target for vandalism and terrorism which could cause severe accidents and chaos.

An extremely reliable technology is required since vehicles are going to turn into drive-by-wire mode (like modern airplanes), without any direct mechanical or hydraulic connection from the driver to the wheels. The Drive-by-wire technology connects vehicle directly to the traffic management, gradually replacing the human driver. Since car is a mobile device, the external communication and control have to rely on wireless communication only. In case of communication failure the vehicle has to be capable of fully autonomic behavior based on its own sensors or it has to return the control to the driver.

8.4 Autonomic electric traffic

The energy and emission aspect of traffic is getting more and more important as traffic represents about 30% of the total power consumption. Since electricity is not a source of energy, so it should not be compared to oil or nuclear energy etc. Instead electricity is an efficient way of producing power, transmitting it over long distances and using it as moving power. With electricity it is possible to separate the three basic processes (production, transmission, usage) and optimize each domain with the best available technology at any given time (figure 4). For example the spectrum of the energy production methods can be renewed without changing the vehicle and charging technology. So the electric approach is both ecologically and technically sustainable over long period of time.

The storage of electricity is still a bottleneck with moving engines like electric vehicle. Although sufficient technology is almost there, it is still expensive. In urban traffic the 90% of trips are less than 50 km, therefore the daily commuting is not a problem. An average sized car with range of 150 km requires about 30kWh battery. This size of battery can be charged with household energy overnight.

There is also need for fast charging methods, which still requires significantly more time than filling a tank with gasoline. For example charging a 30kWh battery with 90kW power lasts about 20 minutes, so it would make sense to locate the stations close to other potential services and activities.

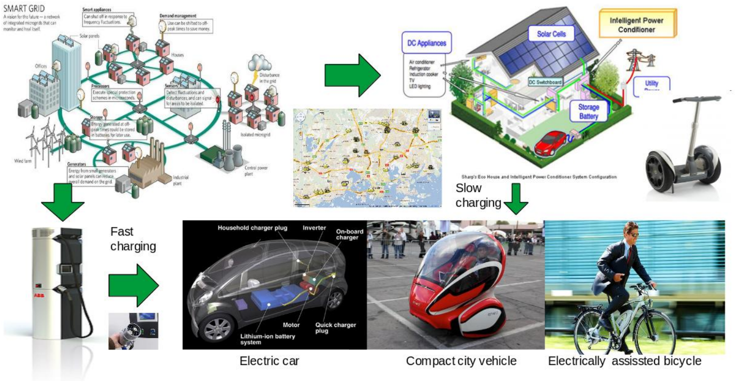

Figure 8.4: Management of energy flows of electric traffic

The positioning of fast charging station should be optimized according to the traffic flows. In fast charging it is important to optimize the charging time, battery duration, and the network load. There should also be optimization of the guidance of electric cars to the charging stations according to the route, state of the battery, available stations and estimated charging and queuing time.

The so called smart grid is optimizing the transmission of electricity and balancing the load of the network. This makes it easier for small ecological producers to connect the grid. The fluctuations on the grid can be compensated with back charging (V2G) , in which the car battery can supply energy to the grid during short peak periods.

As a source of moving power the electric motors offer superior efficiency (90%) compared to internal combustion engines (ICE). The construction of electric motor is simple, durable and compact. The range of rpm is wide and the torque is high starting from zero rpm. There is no need for idle and and the engine doesnt shut down if load exceeds the maximum torque. These features allow a vehicle structure, which is more compact since many mechanical parts become unnecessary like the clutch, gearbox and differential gear. Because of the simplified mechanics, it becomes technically and economically feasible to produce wider spectrum of vehicle sizes. The small electric vehicles can be part of the solution to the lack of space in dense urban areas.

Electric motor can be easily controlled and adjusted very precisely directly with electric circuits communicating with the traffic management systems. This is a most important feature considering the automated and autonomic traffic of the future. The potential of electric moving power is nicely demonstrated in a new vehicle type namely the Segway. It would be absurd even try to implement such an inherently unstable vehicle by using internal combustion engine.

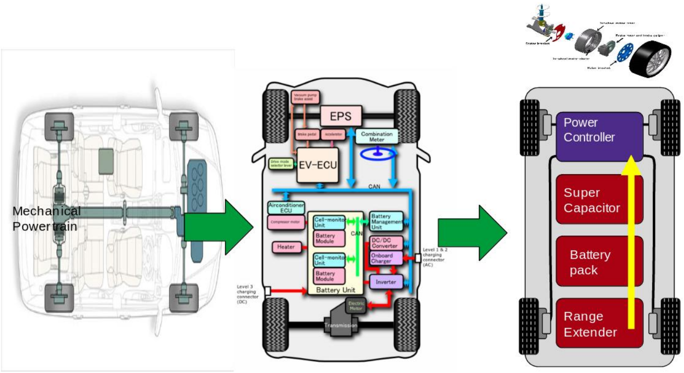

Figure 8.5: Towards more simple and scalable vehicle structure

Due to the lack of charging infrastructure, use of electric power is increasing through various hybrid solutions. In serial hybrid or range extender hydrid (RE-EV), the moving power is always electric. The range extender will be used only in longer trips if fast charging is not available. In this solution the moving power, energy storage and energy production are separated. Therefore the range extender can be implemented by whatever available technology in the future (ICE, turbine, fuel-cells etc.) and it can be used within its optimal operating range. The power of the range extender needs to slightly more than the average moving resistance of the car (say 20 kW). The peak power during accelerations is taken either from battery of from a super capacitor. (figure 5).

The basic structure of the electric vehicles is going to change gradually from the traditional mechanical power train towards a sort of electric power train. In (figure 5) one likely solution is outlined. Every wheel is integrated with a unit consist of motor, brakes, steering and suspension. The electric motor generates the moving power but it is also used in regenerative braking, ESP, etc. Such unit could be produced is large quantities making the car more simple and cheaper as well.

8.5 Discussion

The idea of autonomic computing comes from organic systems. After the 3,5 billion year of evolution, these systems have become extremely complex, but still very energy efficient. Take for example the human body that consists of 10-100 trillion of cells (which are already complex systems as such), but the average power consumption of human body is only about 100 Watts. This energy efficiency is one reason that makes the organic systems sustainable, unlike the man made systems.

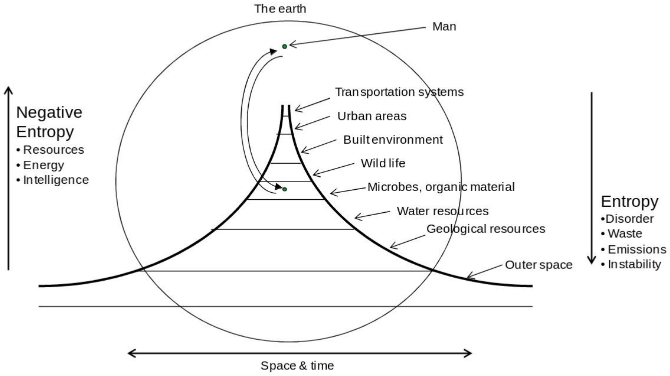

Figure 8.6: Maintaining negative entropy: organic systems vs. man made technology

The main problem with the big cities and their traffic is the sustainability. Cities are not sustainable as themselves, but they suck energy and resources from the surroundings. The autonomic traffic management together with the electric mobility are tools towards more sustainable transportation.

The development of man made systems is a combination of technical evolution as well as intelligent planning. The speed of the technical evolution is very high, while the intelligent planning tends to be a slow process. The adaptation to the future challenges can be either too slow to meet the challenges or too fast potentially leading to instability.

While the man made autonomic systems can have number of autonomic *self-functions, they still fail to maintain the negative entropy without human intervention. The organic systems have solved the equation of maintaining negative entropy by limiting the life span of individuals, but maintaining the slowly evolution of life as a whole. However, the man made systems are neither dead or alive, they consume too much energy and resources and the recycling of them is not as perfect as in organic systems.

There is still a long way to go to get the level of technology even near to the level of organic systems. However, it is still reasonable to make the best effort to improve the present systems towards sustainability. This is of course much wider question than the traffic management only, but traffic has a significant role. The energy consumption, emissions and waste are only one side of the problem, another challenge is the instability, which can be already be seen other fields like in the climate change, in the global economy and politics.

Chapter 9

Incident detection, prediction and management

Contribution by: Andreas Gregoriades, European University Cyprus, Dept. of Computer Science and Engineering, Cyprus.

9.1 Introduction

Traffic incidents are obstructions or restrictions to traffic flow, such as stalled vehicles, accidents, construction and maintenance activities, adverse weather conditions, or special events. It is estimated that a high percentage of traffic congestion is caused by incidents. Incident detection and management is the process of identifying and responding to incidents that aim in restoring the normal traffic flow.

According to the World Health Organization road accidents constitute one of the leading cause of death for people between the ages of 5-44,(WHO,2011). Given the current trends, accident fatalities are projected by 2020 to become the fifth leading cause of death worldwide resulting in an estimated 2.4 million deaths each year (WHO, 2011). At the same time, traffic accidents result in high economic losses due to traffic congestion which in turn leads to a wide variety of adverse consequences such as, traffic delays, supply chain interruptions, travel time unreliability, increased noise pollution, as well as deterioration of air quality. To combat these and the intrinsic accident risks, road safety has emerged as a priority alongside road safety management and forecasting practices. These however, suffer from major limitations and need improvement to effectively tackle this problem. One of the problems faced is data availability for the development of crash prediction and analysis models. This report contributes in this direction through the survey of incident detection and accident risk quantification approaches currently in use.

9.2 Accident Analysis

Inherently, road networks constitute complex dynamic and uncertain systems influenced by human, technological and environmental parameters. Therefore, one of the best ways to understand the causes of road traffic accidents is to develop models capable integrating significant factors relating to human, vehicle, socio-economic, infrastructural, and environmental properties. There are two broad categories of accident analysis methods: the qualitative and the quantitative. The former, despite its limited use, plays an important role in the process of accident analysis, modeling and forecasting. Qualitative analysis is subjective, exploratory and interpretative, while quantitative is based on the positivist philosophy and hence more widely used. Quantitative methods are classified into two principal groups: Time-series forecasting and Causality-based forecasting.

Inherently incident detection and prediction falls under the umbrella of road safety management, the literature of which is categorized into macro- and micro-level approaches. The former takes a holistic view of the road traffic system, where accidents are caused by coordinated events of the systems components which give rise to accident patterns. The latter looks at accidents on an individual component basis and investigates the dynamics of each components supporting sub-elements. Macro-level analyses use statistical techniques to give an aggregated view of historical data and with the use of regression analyses make projections on future system states (DOT, 2000). These are categorized into four groups: averages from historical accident data, predictions from statistical models based on regression analysis, results of before-after studies, and expert judgements by experienced engineers. Each of these methods, however, suffers from significant weaknesses. Estimates from historical accident data suffer from high variability. Estimates from statistical models use data of accidents with roadway characteristics (traffic volumes, geometric designs features) in a regression analysis to predict the expected total accidents in particular locations; this, however, can lead to unreasonable interpretations of the outcomes. Before-and-after studies have been used for many years to evaluate the effectiveness of highway improvements in reducing accidents. However, most before-and-after studies have design flaws which lead to ambiguous results. Estimates from expert judgement suffer from the inability of domain experts to quantify cause and effect (Persaud wt al 1993). Micro-modelling, on the other hand, is based on the paradigm of agent-based simulation where a number of autonomous software agents, embedded with prior characteristics and driving behaviours, are left to interact in a controlled road network environment. Driving behaviours are specified in terms of simple car following, lane changing and gap acceptance rules. The former describes the drivers acceleration and deceleration patterns, i.e. conservative drivers maintain the speed of the leading vehicle while aggressive drivers try to attain their own desired speed. The latter theory describes the behaviour of drivers when changing lanes. In contrast to the macro approaches, micro-simulation is richer and models provide a more accurate representation of road network dynamics.

9.3 Traffic simulation for data coverage

When it comes to incident prediction adequate information regarding the state of the road network is required. When sensors are available these can be obtained directly from the road network in real-time. However, in reality this is never the case. Hence, to achieve optimum data coverage necessary for incident prediction, traffic simulators have emerged as a technology. Traffic simulation is categorized into micro, macro end intermediate simulation. The latter constitute a more accurate technique for traffic flow prediction, a parameter of vital importance to incident prediction.

9.4 Mesoscopic traffic simulation

Dynamic traffic assignment (DTA) is an intermediate-scale simulation technique fine-grained for a better estimation of traffic routing and traffic volume. The DTA produces estimates of traffic flow conditions for every 15-minute time interval of a simulation. These estimates include, traffic flow and speed at link and movement level. Under well calibrated data, DTA estimates can be used as additional explanatory variables in accident prediction models. Historically, DTA was pioneered by the United States Federal Highway Administration (FHWA) through sponsoring the development of two mesoscopic DTA modes the DYNASMART-P and the DYNAMIT, at the University of Texas and Massachusetts Institute of Technology respectively. Parallel to these efforts, Ziliaskopoulos developed the RouteSim mesoscopic simulator and the Visual Interactive System for Transport Algorithms DTA (VISTA-DTA). Currently, many more simulation-based models have been developed around the world as the transport agencies are embracing them as a tool to evaluate various infrastructure and operational network improvements. These include DynusT, Dynameq ,AIMSUN, TRANSMODELER, INTEGRATION and METROPOLIS (Gregoriades et al, 2013). The DTA model used in this study is realized in VISTA (Ziliaskopoulos and Barrett, 2006), which at convergence it reaches a local DUE. The main output of a DTA model is the OD DUE of vehicles trajectories based on six seconds or less simulation time step. Hence, the analyst can aggregate the traffic flow characteristics at the link, movement, path, sub-network, network level as desired.

The principal characteristics of simulation-based DTA models are: 1) A dynamic Origin-Destination (OD) matrix, estimated using a combination of techniques such as, OD surveys, traffic counts, path trajectories via location estimation devices i.e. GPS and wireless roadside vehicle readers 2) The DTA model propagates the OD demand using a mesoscopic traffic simulator cell transmission model at every six seconds or less. Vehicles move in packets from one cell to the next subject to the traffic flow theory laws of density, flow and speed 3) Each vehicle moves along a time-dependent shortest path that is determined at each iteration 4) The model converges to a Dynamic User Equilibrium (DUE) that states that no user can unilaterally improves his/her travel time (cost) by changing his/her departure or desired arrival time and path within the assignment time interval. Therefore, for each path with vehicles and for a specific time interval, each path will eventually have the same travel time as the other paths for each OD pair 5) DTA models converge to a local DUE. Global DUE is computationally intractable while until now no model reported has ever claimed global convergence.

A thorough review of the main characteristics of DTA models is presented by (Peeta and Ziliaskopoulos, 2001). An evaluation of DTA models used the following discriminators: simulation unit (link and/or cell), simulation time step (less/equal to 6 seconds), modeling of signals (pre-timed and/or actuated), stop signs, use of zone connectors, lane connectivity modeling (implicit or explicit), equilibration method (gradient, MSA), iterations needed to reach a DUE (30 to 60), modeling of a generalized cost function, and the computing platform. VISTA is a DUE convergent model that uses the simplicial decomposition algorithm and is the only Internet-based DTA model running on Linux whereas the remaining are Windows/PC based. This study also demonstrates that the interest in implementing DTA models is increasing, while it points to the challenges of calibration that requires substantially more data than Static Traffic Assignment (STA) models and the slow convergence (Mahut et.al. 2009) that requires hours versus minutes for STA models. The main characteristics of DTA models, their differentiation from STA models, the issues of stability and convergence can be found at the primer. The primer provides support to the implementation of DTA models as a tool to estimate the traffic flow conditions at 15-minute time intervals. This necessitates modeling with sufficient accuracy the aggregated demand (in 15-minute time intervals), roadway geometry, traffic control and traveler information devices/services.

9.5 Microscopic traffic simulators

Microscopic traffic simulators may produce additional traffic flow characteristics that may provide more explanatory variables on the causation of accidents such as the distribution of the vehicle speeds, the headway distribution among vehicles, acceleration/deceleration and gap acceptance in lane changing maneuvers. Various microscopic simulators could be employed for accident analysis such as CORSIM, VISSIM, PARAMICS, WATSIM (FHWA, 2011) and others. Their main deficiency over mesoscopic DTA models is that they do not have a true traveler behavior routing component, (Peeta and Ziliaskopoulos, 2001). This is due to the magnitude of the computations that these models need to perform to mimic the driving behavior of each vehicle in the model. These models model traffic by splitting it probabilistically at intersections based on historical records or following predetermined or DTA paths that are non-DUE. Hence, they cannot be used to accurately predict traffic flow conditions based on the DUE principle. A continuously calibrated DTA model utilizing a microscopic traffic simulator that reaches DUE solution, is the best model that could be utilized for traffic flow estimation and prediction on a systematic basis. Yet such a model is not feasible due to its unreasonable computational cost that requires days to converge to a DUE and the unavailability of data to conduct an appropriate calibration.

9.6 Incident detection and prediction

There are many techniques for incident detention namely: statistical, pattern recognition, Catastrophe Theory, Bayesian Networks, Neural networks and video processing algorithms to name a few.

9.6.1 Prediction approaches

Incident prediction can be performed in different ways; scenario analysis (Tsai and Su, 2004; Fleury and Brenac, 2001) is one approach used that stemmed from the complex systems reliability domain. Traditional approaches to road safety include: Comparable evaluation of Road Safety Audit, Road Safety Inspection and Road Safety Impact Assessment. The main disadvantages of these methods are cost and time to carry out. The underlying component of a scenario is the notion of an atypical event. An event constitute an element of an accident scenario sequence, and there may be good reason to believe that similar events have caused similar accidents in the past, but that is not sufficient to establish that this event alone was a cause of the accident at hand. Over the past 15 years or so there has been increased interest in causal inference as a component of artificial intelligence, and one especially useful approach is based on what Pearl (1988) calls a causal model which inherently constitute the backbone of BN technology that is employed in this study. Scenarios are used to designate a prototype or a model of an accident process characterized by chains of facts, actions, causal relations and consequences in terms of damage to people and property. Scenarios are used to design and improve prevention strategies, either by studying past experience or by seeking to foresee chains of situations leading to catastrophes. Therefore, scenario analysis as a causality investigation technique it examines event patterns that can occur either sequentially or in parallel. Scenarios can be expressed as instantiations of nodes on BN models(Sutcliffe and Gregoriades, 2007) or event specifications in Event trees, Fault trees (Zheng and Liu, 2009). Automated scenario variation is a technique used by (Gregoriades et al, 2011) to identify black spots on a road network by systematically changing seed scenarios to exhaustively analyze all possible conditions at different sections of the road network. An evaluation of black spot assessment methods by (Huang et al 2009) provides insightful suggestions on pros and cons of each approach. Scenarios are usually expressed as event sequences that combine information from the environment, the road users, the weather or the road infrastructure. Modeling scenarios using Event and Fault trees however is based on the assumptions that accidents are modeled as binary events that are statistically independent. These assumptions restrict the use of these methods to static, logic-based modeling. Tree-based methods therefore are not suitable to describe influencing factors with more than two potential states and make it difficult to represent the relationships among factors. In road accidents analysis some factors may have more than two states, for instance, driver behavior and traffic conditions have a wide range of possible states. In addition, the relationships among factors contributing to an accident cannot be easily represented by means of logical gates. Thus, scenarios expressed in tree-based methods are not suitable for road accidents analysis.

In complex systems such as the road networks, where humans and machine agents collaborate, the likelihood of committing an error by either party needs to be investigated. Based on this, there are two broad categories of accident analysis using scenarios: the human related accidents and the machine induced accidents. In practice accident forecasting using scenarios is often combined with other forecasting methods, taking into account possible variability in single scenarios as well as possible relationships between different scenarios. However, the main problem in scenario-based approaches is the lack of reliable techniques to automate the generation of sufficient set of scenarios to assess systems safety (Gregoriades et al 2005). Several approaches have been proposed that have ended up with too many scenarios that drawn the safety assessment process in excessive detail.

9.6.2 Bayesian Network (BN) for incident prediction

BNs are directed acyclic graphs of causal influences, where the nodes represent random variables, and the arcs represent (usually causal) relationships between variables. The two main components of BN are the causal network model (topology) and the conditional probability tables (CPT). The model causal relationships are expressed as directed acyclic graphs. Variables are denoted by nodes in the model and can have any number of states, so the choice of measurement scale is left to the analysts discretion. Causal relationships among variables are described by arcs among nodes. CPTs describe the prior knowledge of the problem domain and explicitly specify the causal dependencies in terms of conditional probability distributions (Jensen, 2001). Parameterising the CPTs is often the most demanding task in BN development, as the number of probabilities can be counted in hundreds or even thousands (Druzdzel and Van-der-Gaag, 2000) . CPTs can be inferred from data when available or subjectively specified by experts. The former is more objective, however, it is unlikely to have all the data needed to specify all CPTs in a model. Hence, the use of experts is sometimes imperative. BNs can be used in two main types or reasoning: bottom-up/diagnostic and top-down/predictive. The former infers the most likely cause given evidence of an effect. While the latter, "top down", deduces the probability that a certain cause would have given a specific effect.

Example BN topology

Formally, a BN encodes the joint probability distribution over a set of n variables X = X1,,Xn and escapes from the combinatorial explosion problem. Therefore, let us denote by Xi a random variable, and by i the set of parent nodes of Xi. Then the joint distribution of X can be expressed as the product of the conditional distributions of each variable given its parents, where x represents an instantiation of X, i an instantiation of i, and xi denotes the state of Xi,: (1) The conditional probabilities described by equation (1) are presented in the CPT. When the topology and CPTs have been completed, Bayes theorem can be used to diagnose a cause given an effect or the chain rule (1) to predict an effect given a number of causes. The theorem is shown in equation (2): (2) where, p(xi/xj) = posterior (unknown) probability of xi given xj p(xj/xi) = prediction term for xj given xi p(xi) = prior (input) probability of xi p(xj) = input probability of xj or, less formally: (3) The example in Figure shows two influences on accident risk (AR), namely, traffic flow (TF) and traffic control (TC). Let us denote by W the AR, M the TF, and S the TC. Their corresponding states are described by w, m and s respectively. The variables can have any number of states, so the choice of measurement scale is left to the analysts discretion. Let us denote by nW, nM and nS the number of states for W, M and S respectively. In the following sections, we assume that the variables can take three discrete states (nW = nM = nS = 3), namely, high (h), medium (m), and low (l). Therefore, based on the above example, to diagnose (bottom-up) the probability that traffic flow is mj given that we have evidence that accident risk is wk, we use the Bayes rule: (4) In predictive reasoning the chain rule is applied to calculate the likelihood that accident risk is wk , given evidence of traffic flow is mj and traffic control is si,: (5) Input evidence values are propagated down the network, updating the values of other nodes as explained above. The network predicts the probability of inquiring variable(s) being in particular state(s), given the combination(s) of evidence entered. BN models are extremely computation-intensive when the topology and the variable states increase. Recent evidence propagation algorithms, however, exploit graphical models topological properties to reduce computational complexity (Pearl, 1988, 2009). These are used in several commercial inference engines such as HUGIN (Jensen , 2001). One limitation of BNs is that they have to conform to a strict hierarchy since cycles lead to recursive and non terminating propagation of probabilities by the algorithm. This imposes some compromises in modelling influences, which can be partially overcome by introducing additional input nodes to model cyclic influences, although this increases complexity of the network and the control process for the algorithm.

9.6.3 Applications of BN in traffic accidents

BNs have gain widespread attention as a method for analyzing and predicting accidents. They use scenarios which represent instantiations of variables in their causal network. BN have been used to establish complex relationship between the accident and casualties of accident as well as the correlations among various causal factors. BN are used to predict the severity of accidents including minor, critical and fatal accidents. Based on the characteristics the accidents, factors contributed to accident severity including the type of accidents, driver age, lighting and numbers of injuries were identified by inference. BN based intersection safety evaluation models can take into consideration expert knowledge in combination with historical data. Similarly BN are used to utilize traffic accident, traffic flow, infrastructure and environmental data to identify and rank hazardous sections on roadways.

Other related applications of BNs include the use to model road accidents and accordingly make inferences for accident analysis. BN could also used to predicting road accidents through intelligent surveillance of vehicle kinematics. BN quantitatively model the causal dependencies between traffic events (e.g. incident) and traffic parameters. Using real time traffic data as evidence, the BN can update the incident probabilities.

9.6.4 Artificial Neural Networks (ANN)

Neural networks are frequently used to classify patterns based on learning that is inferred from historical data. Different neural network paradigms employ different learning rules, but all in some way determine pattern statistics from a set of training data and then classify new patterns on the basis of the knowledge learned.

9.6.5 Probabilistic Neural Networks (PNN)

The PNN is tailored to accurately predict categorical outputs. Based on Bayesian classification, it non-parametrically creates non-linear decision surfaces (boundaries) between classes; these boundaries approach the Bayes optimal for increasing sizes of the training set.

The PNN four-layer architecture comprises the input units in the first layer. The number of input units equals the input pattern dimensionality, each unit simply delivering the normalized input pattern values to the pattern units of the second layer. The pattern units equal in number the cardinality of the training set, each unit encoding one pattern of the training set and independently estimating the distance between the input and encoded pattern. The calculated distances of all the patterns units are subsequently transformed by an exponential function and passed on to the summation units of the third layer. These units equal in number the classes appearing in the training set, with each unit receiving input only from the pattern units representing training patterns from the same class as the unit. The inputs to the summation units are summed and fed to the decision units of the fourth layer. The number of decision units equals the output dimension; each unit is connected to the summation units describing the different classes for the particular dimension and selects the class of the connected summation unit with the largest contribution.

The PNN typically employs all the training patterns (stored in the pattern units of the second layer) for classifying a novel pattern. The amount of influence of each training pattern on the output is a combined function of (a) its distance from the novel pattern, and (b) the smoothing parameter [0,1]. The smoothing parameter appears in the exponential function of the pattern units and controls the extent of influence of each training pattern on the PNN classification process and, consequently, on the shape of the decision surface. Accordingly, the decision shape varies from extremely rugged for small values (peaking at each training pattern and dropping swiftly as the distance from the training pattern grows) to an increasingly smooth surface for rising values. Selection of an appropriate value is important for successful PNN generalization, i.e. for the accurate classification of novel patterns.

The PNN has a number of important advantages for prediction tasks. A rough decision surface can be created by a(n initially) limited training set, even in the presence of noise-contaminated and/or erroneous patterns. The PNN is significantly faster to train and easier to incrementally retrain than other ANN architectures such as back-propagation: novel training patterns can be directly incorporated in the PNN at any time by the addition of pattern units (one per novel pattern) and the creation of appropriate connections to the input and summation layers, whereby the decision surface becomes locally fine-tuned; the deletion of training patterns is just as straightforward via the removal of units and connections.

9.6.6 Decision Trees (DT)

The DT constitutes a popular classification methodology that has become a prevalent tool in data mining and machine learning.

Given a database of patterns with many input parameters (attributes according to DT terminology) and an output (represented by continuously or categorically expressed classes), the DT is induced/constructed/learned in a top-down hierarchical, exhaustive and recursive manner. The parameter to be tested at each step (DT node) is selected such that a specific selection measure is maximized. The most prevalent parameter selection measure is information gain, i.e. selection of the parameter (and value) that effectuates the greatest entropy reduction in the dataset (or partition thereof) by dividing the latter into maximally separable parts. Information gain minimizes the expected number of tests (and, consequently, DT nodes) and guarantees that a simple - although not necessarily optimal - DT be found. Another salient difference in DT induction is whether a single or multiple parameter values are selected at each node, whereby the node branches out to two or more nodes of the next level (in other words, the dataset partition is split into two or more sub-partitions). Clearly, the number of DTs that can be constructed for a given dataset is massive, with the construction of an optimal binary decision tree constituting an NP-complete problem. To this end, a variety of efficient DT induction approaches have been developed to date.

The basic strategy for DT induction is described as follows. Initially the DT exhaustively searches the database for the parameter whose value(s) best partition(s) the dataset according to the chosen selection measure. The selected parameter and value(s) constitutes the top DT node, with as many branches and second-level nodes emanating from it as there are tests performed on the parameter. These tests partition the database and each partition is assigned to a second-level node. If each partition corresponds to patterns from a single class, DT construction is complete. Otherwise, the aforementioned procedure is recursively repeated for each node of the most recently created DT level that does not contain patterns from a single class and until (a) either every partition contains patterns from a single class (i.e. classification can be faultlessly performed by descending the DT through the appropriate levels and nodes), or (b) no parameters remain for further partitioning. In order to optimize generalization and maximize classification accuracy, DT pruning techniques are applied; pre-pruning trims the DT by halting its construction early on, while post-pruning deletes nodes and removes their branches after the entire DT has been constructed.

Following DT induction and pruning, a novel pattern is classified by descending each level of the DT until a terminal node is reached, whereby the pattern is assigned to the same class as the training patterns that are assigned to that terminal node.

A DT can be further characterized as a regression or classification tree when continuous or categorical, respectively, outputs are handled. Accordingly, the most popular DT methodologies are: ID3 (Quinlan, 1986), which is focused upon categorical output parameters. Owing to the fact that maximization of information gain effectuates the optimal data partition for the data available at the particular node only, the selected test may not be optimal in the long run. The lack of backtracking implies that ID3 may not always produce the best DT in terms of classification. C4.5 (Quinlan, 1993), which can handle both continuous and categorical output patterns, splitting each selected parameter into exactly two partitions via an appropriately selected1 parameter values. The ability to handle noisy data and data with missing values constitutes another improvement of C4.5 over ID3.

The DT is appealing as it explicitly describes a hierarchy of easy-to-understand rules that can swiftly classify novel input patterns. Each rule creates a linear hyperplane that separates the input parameters according to the selected parameter value(s). The hierarchy further provides an indication of the importance of the various input parameters according to the level at which they appear in the DT. On the down side, DT learning is computationally intensive, especially for non-binary categorical input parameters. This problem becomes especially accentuated for continuous input parameters, whereby the resulting DT may remain quite big, even after pruning.

9.7 The human element

Most of incident prediction approaches stem from an engineering perspective and therefore ignore the softer aspects of such systems, the people. Contemporary safety literature (Gregoriades et al 2010) has reached a consensus on the importance of the human element in road safety. Accidents in general occur due to human misjudgement or human error (HE). It has been reported that HE was the sole cause of road accidents in 57% of all cases and was a contributing factor in over 90% (Reason 200). People driving in a highway are bombarded with information. Most of this information is visual input, such as road geometry, other vehicles, pedestrians, scenery, etc. At the same time, the driver may be processing other inputs relating to auditory resources, such as communicating with a passenger, listening to the radio, etc. This information creates a demand for cognitive resources. In the case that the demand exceeds available resources then the driver attends to only a subset of the available information to make decisions. According to Mille (1956), people can process 7 plus or minus 2 discrete information chunks at a given point in time. This approximates to the boundary of our cognitive capacity in terms of memory. Therefore, increased demand for cognitive resources may result in drivers failing to attend to critical information on the road. Humans are information processing systems with a number of information flow channels (visual, auditory, tactile) sampling various information sources (e.g. a navigation system display, the forward view through the windscreen) which have various bandwidths (e.g. high-density traffic will require a higher sampling rate than low-density traffic). Our cognitive capacity is limited, and in return there is an upper threshold to the amount of information we can process per second and channel. Therefore, we tend to share our attention among a few information sources. When overloaded, we neglect to sample some of the information sources (e.g. the rear-view mirror) or miss information (e.g. the fact that the car ahead is slowing down) because we sample the information source too infrequently. Moreover, we are limited in our ability to manipulate the information we take in, and in the rate at which we can make decisions. Therefore, in an unexpected event an overloaded driver is less capable of dealing with the situation safely.

Fulle (2005), also expresses accident likelihood as a function of the drivers cognitive resources and task-demand in the driver-road system. The underlying theory of his approach is sensation seeking and how it affects driving behaviour. His model uses task demand and capability as two intertwined factors that contribute to sustainability in driving performance. According to this model, when a drivers capability exceeds demand, the task is considered easy; when capability equals demand the driver is operating at the limits of his/her capability and the task is difficult. When demand exceeds capability, then the task is too difficult and the driver fails at the task, which leads to loss of control and likely collision, or the vehicle careering off the roadway. Moreover, according to this model, drivers may modify the driving task demand in order to reach and sustain the desired level of sensation. Therefore, the level of arousal constitutes a criterion that feeds into the determination of target task difficulty. Therefore, extroverted individuals are more likely to seek enhanced external stimulation, and hence they may be more likely to accept higher levels of task demand that could lead to loss of control and collision.

An alternative cognitive modeling approach developed by Anderson et al (2004) uses a representation of both the human perceptual system and the external environment. The ACT-R model provides a systematic approach to integrating all aspects of human cognition and hence accounts for the perceptual factors at the level of the driving. The architecture consists of a set of perceptual-motor modules (e.g. motor and visual), declarative memory, procedural memory, buffers, and a pattern matcher that work together to model human-like cognition. Declarative memory in ACT-R is represented as chunks of knowledge, whereas procedural memory consists of if-then rules. Applications of ACT-R in road safety, include the evaluation of the effects of in-car multimedia interfaces on drivers behaviour. Other cognitive architectures, such as Executive-Process/Interactive Control (EPIC) (Kieras et al, 1997), account for human information processing. EPIC provides a framework for constructing models of human-system interaction based on human perceptual/motor performance, cognitive modelling techniques, and task analysis methodology, implemented in the form of computer simulation software. Human performance constitutes one of the principal influences of accidents in complex systems. Clearly, road networks are classified as such and hence the human dimension needs to be adequately addressed in these. However, despite these findings, limited effort has been reported that uses human performance research in predicting road accidents and assessing road safety. Complex systems safety assessment techniques use human reliability and human performance theories as the driving force, together with system resilience assessment through investigation of plausible system pathways that could lead to failure (Hollnagel, 1998)

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