SECTION 3: External Factors, Environmental Benefits and Application Scope

This section will focus on issues of system liability and legal, institutional and political concerns of potential ARTS systems. It will produce details of the quantification of benefits of ARTS infrastructure, and investigate the relationship between ARTS and traditional systems engineering approaches.

Theme 3.1: External System Characteristics

3.1.1 Introduction:

External system characteristics, such as trust, reliability, robustness, security within ARTS systems; the wider implications of the introduction of self-managing systems with respect to national legal and regulatory frameworks for Transport, and EU legal frameworks.

The use of automation in transport systems (by Tiziana Campisi, Fabio Galatioto and Giovanni Tesoriere)

The oldest form of automation in transport is the use of autopilot in aircrafts. It is a system used shortly after takeoff, during the climb, cruise and in the approach phase. Some more sophisticated models can accomplish the landing automatically (Autoland). There are different types of autopilot depending on:

- the number of axis on which they work,
- the type of aircraft and
- its complexity.

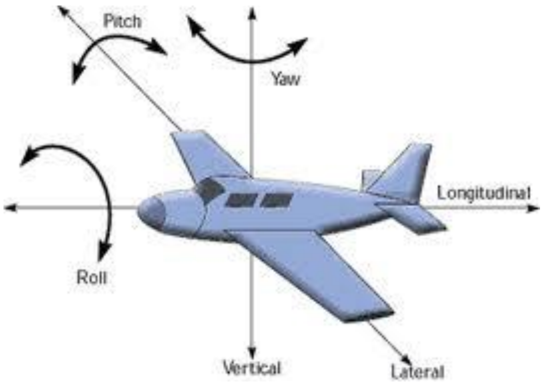


Figure 1. Principal aircraft manoeuvre

Autopilots have the main purpose of reduce the pilot workload, maintaining constant some aircraft parameters (heading, course, altitude and vertical speed). It is an electro/mechanic device that can drive a vehicle without any human intervention. Most people associate the autopilot specifically to airplanes, but autopilots for boats and ships are in the same principle, have the same purpose and work in a similar way.

3.1.2 State of the Art and Current Research Directions

The use of automation in transport systems

Although autopilots can work independently from human intervention, pilots have to pay attention all the time. The first autopilot was built by the Sperry corporation and was designed to allow the aircraft to fly straight and at a constant altitude, and working up to 80% of the flight duration.

Today autopilots are more sophisticated and can be used in many phases of the flight, including automatic collisions avoidance systems (TCAS). Autopilots are in practice software installed into the aircraft, they can also handle unpredicted circumstances but with less flexibility of a pilot, while autopilots usually consume less fuel than pilots.

Aircraft position and stability are referred to an Inertial Navigation System, however it can accumulate errors overtime, then a Satellite Navigation System coupled with a Kalman filter are used to correct these errors. The typical hardware of an autopilot is made by 5 processors 80386 (the cheapest, more widespread and resistant to radiations), it is preferred to newer versions because it is cheaper, safer and more reliable. The collected experience from the automatic systems in the aircrafts can be employed for the application of similar systems including the base autonomic properties in the road transport vehicles.

Safety and Security

The correct operation of the autopilot is critical to the safety of the aircraft. They are therefore designed to cope with faults, programming errors and each other eventualities to avoid a crash. Airliners are usually equipped with at least ***one of two redundancy autopilot***, this type of redundancy is called "fail-operational".

The special operating system that runs on the processor provides a virtual system of itself, in this way the software does not interface directly with the aircraft electronics, but acts on a software simulation of the latter. In this way errors can be detected and discarded before the commands are implemented or the process stopped and restarted from a correct copy.

Other safety measures are: repeating twice the same mathematical operation and checking that the results are the same; each of the autopilot processes runs more identical copies distributed on different computers. Extreme values (outliers), which are usually wrong, are excluded before they are used to control the plane.

Some autopilots also use a diversity of project. Then on top of running the processes on different computers, and in multiple copies, they are also designed by different groups of engineers. This is because it is very unlikely that different groups make the same mistakes. However, with the rapid development of IT, software is becoming more complex and expensive, and the latter approach is less common because few manufacturers can afford it.

According to recent studies, the number one cause of accidents in aviation around the World is no longer the **Controlled Flight Into Terrain**, but the **Loss of Control**: the loss of basic references and control of the aircraft, coming to stall, to excessive inclination, to exceedences of maximum speeds.

In this context the FAA (U.S. agency that deals with aviation regulations) has recently issued a series of recommendations on training in basic piloting. In fact, for many drivers of the latest generation, the training focuses on human-machine interactions rather than on the parallel control of the trajectory between the pilot and on-board automatisms. It is very difficult to control an autopilot that is slaved to the on-board computer as FMS , GNS , etc. and understand or anticipate what moves the computer will perform during the approach, so that would be possible to intervene and eventually take control of the plane, releasing the autopilot. A common expression from pilots is: “the computer is wrong" when they face a deviation from the planned trajectory.

An autopilot can maintain altitude, course, speed and move the aircraft better than a pilot, but cannot make decisions in a complex environment evolving rapidly.

There are various cases of incidents called CFIT (Controlled Flight Into the Terrain) when a fully functional aircraft go to impact with the ground, with the unconsciousness of its pilots; or quasi-incidents so-called CFTT (Controlled Flight Towards the terrain), which differs from the previous one for the simple fact that the chain of events that led the dangerous situation is broken in some way and the crew regained awareness of his position, he manages to put in place an evasive manoeuvre. CFIT is one of the most common causes of aircraft accidents. The reasons why a CFIT can occur are varied, and range from too much trust given to automated systems on-board to the excessive workload, from the pilot fatigue to the wrong instructions given by the land controllers from the mistakes of interpretation of certain signs instrumental to lack of knowledge of the places flew over, or, as usually happens, by a deadly cocktail of these and other reasons.

Example of recent recommendations from the FAA

While the increasing level of cockpit automation and more frequent use of autopilots have helped improve operational safety and flying precision, it has also raised concerns that pilots are losing proficiency in their hand-flying skills. A recent Safety Alert For Operators (SAFO) issued by the Federal Aviation Administration (FAA) addresses that concern by recommending that pilots take control of their aircraft more often.

The SAFO recommends that professional flight crews and pilots of increasingly advanced aircraft should turn off the autopilot and hand-fly during low-workload conditions, including during cruise flight in non-RVSM airspace. It also recommends operators should promote manual flight operations when appropriate and develop procedures to accomplish this goal.

Auto flight systems are useful tools for pilots and have improved safety and workload management, and thus enabled more precise operations. However, continuous use of auto flight systems could lead to degradation of the pilot's ability to quickly recover the aircraft from an undesired state. The SAFO adds that, though autopilots have become a prevalent and useful tool for pilots, unfortunately, continuous use of those systems does not reinforce a pilot's knowledge and skills in manual flight operations.

Automation may mask many subtle but growing problems that the aircraft might be experiencing. When that automation reaches its limits and the autopilot hands back control of the aircraft to the pilot, the flight crew must be prepared and ready to respond.

The SAFO adds that flight crews should work with operations personnel and others at their companies to ensure that the content of this SAFO is incorporated into operational policy, provided to pilots during ground training, and reinforced in flight training and pro.

The Autopilot Problem

The autopilot problem is that the FAA regulations have almost totally restricted an airplane owners choice for installing an autopilot in a certified airplane. In some less popular models of airplane there may be no choice at all. The FAA’s contribution to this problem is its certification rules. Long-standing certification rules require that any autopilot be extensively tested in every individual model of airplane before it can be approved. The autopilot flight testing covers essentially the entire normal operating envelope for the airplane. Autopilot failures must be introduced in flight to be sure the autopilot does not fly the airplane into an unsafe attitude or airspeed before the human pilot can recognize the failure and disengage the autopilot.

In almost every case the autopilot manufacturer must make electrical and mechanical changes to the autopilot system to meet the certification rules. For example, one airplane may need more torque from the servo to move its flight controls so that requires more electrical power and a different mechanical clutch and capstan to connect the servo to the controls. Each change must then be flight tested and documented, and the testing only satisfies certification rules for that specific model.

Unlike most other avionics equipment that is eligible for installation in a huge range of airplanes once certification testing is completed an autopilot approval is limited to a single model. The autopilot manufacturer has at best a very small potential market after the certification investment has been made. Because of this cost and hassle newly designed, new technology autopilots are very rare. When they do come along such as the new Garmin GFC 700 that is part of its flat glass avionics system, the autopilot is only certified in current production airplanes because that is what makes economic sense.
The FAA's certification rules made some sense when autopilots were not very smart analogue devices that needed careful adjustment of gains and servo velocities and torque and so on to fly properly and safely. But digital electronics and microprocessors changed all of that. A newly designed autopilot can be "smart" and can teach itself to fly the airplane and store that information in memory. Certification of a current technology autopilot could be low cost and simple if the FAA would adjust its rules to match advances in electronics.

Use of automated people mover
The term **people mover** (or **automated people mover**, APM) means a public transportation system of limited size, automatic and moving in its own lane/road (complete separation from other transport systems and traffic). They are designed and used for point-to-point services to connect, for example, airport terminals, other infrastructure (eg hospitals), to the metro.
These systems and technologies can also be used for other purposes, different from public transport, over short distances. In any case, the technologies used may also be different as the term people mover reference is made to the service and not the technology. Other technologies used are the railways suspended (such as the Skytrain) or VAL technology. In Italy there are two operating systems people mover: one in Milan that connects the San Raffaele hospital to the subway (called MeLA) and Venice linking together the Ankle Boots and Piazzale Roma, while 2 others systems are operating in Pisa and Bologna, where in both cases they are connecting the railway station of the city with the airport.

The **Drive Me project** will start in 2014 and will study the necessary technologies and the development of the interface to have automated cars by 2017. The key aspects to consider will be: the social and economic benefits, the necessary infrastructure, the behaviors in the traffic of vehicles with automated driving, the reaction of the people on-board and the type of confidence of citizens with this way of moving. The vehicles Drive Me correspond to the definition of Highly Autonomous Cars provided by the Federal Highway Research Institute (BASt) in Germany. In practice, the responsibility for what happens on the road is not very different from now: in the event of an accident responds who was in the vehicle, because automatic guidance can be canceled at any time.

Another project is **Google's driverless car**, a Google project that uses technology to create cars without drivers. The project is currently led by engineer Sebastian Thrun, director of the Stanford Artificial Intelligence Laboratory and co-inventor of Google Street View.
(http://money.cnn.com/magazines/fortune/storysupplement/google-self-driving-car/)

Taxis that drive themselves are beginning to replace traditional means of transport. In the town of Milton-Keynes, north of London, will be used soon 100 driverless units to replace its noisy and polluting public transport systems. This vehicles, called **pods** , can carry up to four people at a time at a maximum speed of 20 km/h along a track. In reality, these "automatic taxi " have already been used within London Heathrow airport, although on a closed circuit track, and in two years never occurred an accident. England is once again a pioneer of new technology, even if Volvo, Mercedes and Nissan have announced the arrival of their proposed cars (not Pod going along a track) with autopilot by 2020.

Autopilot on boats and trains

The autopilot is now common on many boats and trains.

For boats it consists of a servo (lock) that controls the rudder to maintain a specific route set by the helmsman. On the most recent version it is possible to set the autopilot control with reference to the compass (on a route) or with reference to an anemometer (on an angle of the relative wind), in this second case, the boat follows the wind and its variations, and not a route. It is an useful tool, but requires a lot of attention and sensitivity to instability conditions due to the sea and the wind.

For trains the **Automatic Train Operation** (ATO) is an operational safety enhancement device used to help automate operations of trains, but mainly guide way transits and subways which are easier to ensure safety of humans. Most systems require maintaining a driver (train operator) to mitigate risks associated with failures or emergencies. Many modern systems are linked with **Automatic Train Control** (ATC) and in many cases **Automatic Train Protection** (ATP) where normal signaller operations such as route setting and train regulation are carried out by the system. The ATO and ATC/ATP systems will work together to maintain a train within a defined tolerance of its timetable. The combined system will marginally adjust operating parameters such as the ratio of power to coast when moving and station dwell time, in order to bring a train back to the timetable slot defined for it.

According to the International Association of Public Transport (UITP), there are 5 Grades of Automation (GoA) of trains:

- GoA 0 is on-sight train operation, similar to a tram running in street traffic.
- GoA 1 is manual train operation where a train driver controls starting and stopping, operation of doors and handling of emergencies or sudden diversions.
- GoA 2 is semi-automatic train operation (STO) where starting and stopping are automated but a driver in the cab starts the train, operates the doors, drives the train if needed and handles emergencies. Many ATO systems are GoA 2.
- GoA 3 is driverless train operation (DTO) where starting and stopping are automated but a train attendant operates the doors and drives the train in case of emergencies.
- GoA 4 is unattended train operation (UTO) where starting and stopping, operation of doors and handling of emergencies are fully automated without any on-train staff.

The use of Unmanned Aerial Vehicles (drones)

Traditionally used for military purposes, during last decade has been a broad effort, mainly in the U.S. but also internationally by several organizations to craft regulations enabling the safe operation of UAVs. Current federal regulations governing unmanned aircraft are limited in scope, and the lack of regulations is a barrier to achieving the full potential benefit of UAV operations. The results of a safety analysis carried out in 2005 indicate that it may be possible to operate small UAVs with few operational and size restrictions over the majority of the United States. As UAV mass increases, mitigation measures must be utilised to further reduce both ground impact and mid-air collision risks.

Unmanned Aerial Vehicles (UAVs), as an aerial traffic information gathering platform, have become subject of research and pilot applications in transportation planning, engineering and operation. They could be an effective airborne surveillance system for rapid and low costs deployment.

However, there are also dangers and pitfalls of using UAVs in transport application as by definition they should fly over urban and congested areas. For example, there are potential risks of clashes, low image/video quality due to wind and/or selections of different UAV technologies and sensor types. These dangers and pitfalls may not be fully reflected in the literature and could not be fully realized without personal flying experience. As such, UAV may not be used for all transportation applications, and not all UAV applications are as cost-effective as the tradition methods.

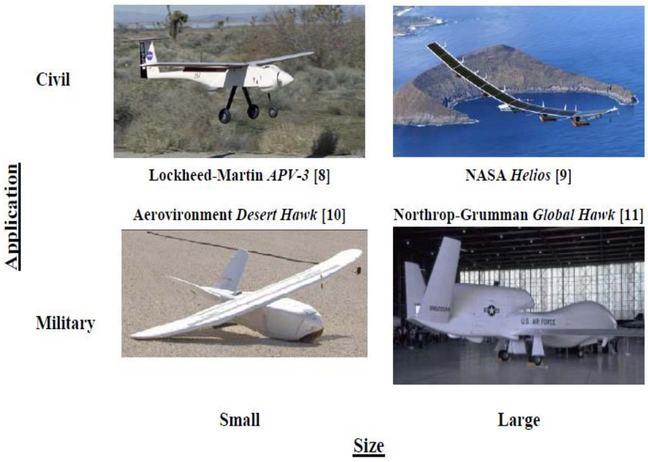


Figure 2. Examples of drones or UAVs

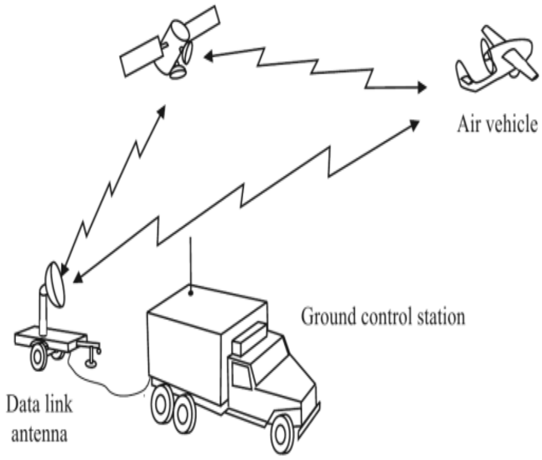


Figure 3. Generic UAV System

The use of automation in transport systems

In the implementation of automatic and autonomous systems in road vehicle, we envisage several challenges. In fact cars without driver will have to move freely on the street, rather than on dedicated tracks, this may have new and unexpected consequences in the implementation of such automation. The U.S. state of Nevada is the first in the world that has approved regulations that indicates the requirements that manufacturers have to meet to test the "driverless" cars on the roads, such as those tested currently by researchers at Google with Toyota and BMW.

These are rules that only allow testing of these vehicles, which are currently not yet ready for sale. Other U.S. states, such as Florida and Hawaii, are considering whether to issue such rules for beta testing driverless car equipped with radar, sensors and software to drive the vehicle in an automatic way. The legislation indicates that the manufacturers will have to pay a deposit between 1 and 3 Million dollars, depending on the number of cars expected to be used in the tests, also they must communicate in advance their specific programs, and the expected dates and any desire to conduct tests on city streets rather than in adverse weather conditions such as fog, rain or snow. The vehicles should have two people on board, with the ability to take control in case of need, and be equipped with a black box that records the sensor data.

Another challenge will be to understand how much redundancy should be implemented in a "driverless" car and if a system like the one implemented in the aircraft, where the software does not interface directly with ever the control electronics of the aircraft, is feasible and economically viable. Finally, the aspects of driver behavior is another challenge especially for those vehicles that will have to move in urban areas thus interacting with other road users such as cyclists and pedestrian.

3.1.3 Actions for the ARTS Community

ARTS and the 2010 European Directive on Intelligent Transport Systems (ITS) **(K.Stoilova)**

European Commission (EC) published White Paper on Transport as a direction for the development of the European Transport Area in the Future [1]. EC discusses three principal transport segments: medium distances, long distances and urban transport. Responsibilities of this have different institutions: the EU, Member States, regions, cities, industry, social partners and citizens.

As the transport is fundamental to our economy and society, effective action requires strong international cooperation. The transport systems of the eastern and western parts of Europe must be united to fully reflect the transport needs of the citizens. The EU and Governments need to provide clarity on the future policy frameworks.

Oil will become scarcer in future decades and its price will increase. The EU appealed to drastically reduce world greenhouse gas (GHGs) emissions with the goal of limiting climate change below 2ºC. EU transport still depends on oil and oil products for 96% of its energy needs. Transport has become cleaner, but increased volumes mean it remains a major source of noise and local air pollution. New technologies for vehicles and traffic management will be key to lower transport emissions in the EU as in the rest of the world. Transport infrastructure has to be planned in a way that maximises positive impact on economic growth and minimises negative impact on the environment. Transport has to use less and cleaner energy, better exploit a modern infrastructure and reduce its negative impact on the environment and key natural assets like water, land and ecosystems.

Combination of efficient modes of mobility should be applied using the instruments of information technologies. Future development must rely on [1]:

- "*Improving the energy efficiency performance of vehicles across all modes. Developing and deploying sustainable fuels and propulsion systems;*
- *Optimising the performance of multimodal logistic chains, including by making greater use of inherently more resource-efficient modes, where other technological innovations may be insufficient (e.g. long distance freight);*
- *Using transport and infrastructure more efficiently through use of improved traffic management and information systems*.

  Better modal choices will result from greater integration of the modal networks: airports, ports, railway, metro and bus stations, should increasingly be linked and transformed into multimodal connection platforms for passengers. Online information and electronic booking and payment systems integrating all means of transport should facilitate multimodal travel. An appropriate set of passengers' rights has to accompany the wider use of collective modes."

Different types of transport are reccomended for different distances. Freight shipments over short and medium distances (below 300 km) will remain on trucks. For medium and

long distance freight the main part is related with the rail transport. In longer distances freight multimodality has to become economically attractive for shippers. The development of the seaports, representing logistics centres with land connections is important to handle increased volumes of freight both by short sea shipping within the EU and with the rest of the world.
Optimisation of multimodal logistic chains with greater use of more energy efficient modes is expected.
The maritime and aviation sectors have to be optimised and reducton of CO_2 emissions from maritime transport by 40% by 2050 compared to 2005 levels is expected.

Cities suffer most from congestion, poor air quality and noise exposure. Urban transport causes about a quarter of CO_2 emissions from transport and that is why public transport, cycling and walking have to be the preferable choice. Development of appropriate fuelling/charging infrastructure for new vehicles is necessary.

The use of Intelligent Transport Systems contributes to real-time traffic management, reducing delivery times and congestion for last mile distribution. The use of electric, hydrogen and hybrid technologies would not only reduce air emissions, but also the noise.
An efficient framework for transport users and operators, an early deployment of new technologies and the development of adequate infrastructure have to be implemented.
Transport research and innovation policy should increasingly support in a coherent way the development and deployment of the key technologies needed to develop the EU transport system into a modern, efficient and user-friendly system. EC funded researches about air traffic management system, European rail traffic management and information system maritime surveillance systems, River Information Services, intelligent transport systems, and interoperable interconnected solutions for the next generation of multimodal transport management and information systems (including for charging) which have to be deployed.

Innovative mobility planning and patterns will be developed. They have to give information on all modes of transport (travel and freight), their combined use and their environmental impact. These systems have to include smart inter-modal ticketing with common EU standards. Several types of planning are needed according to p.49 of [1]:

> *"In the urban context, a mixed strategy involving land-use planning, pricing schemes, efficient public transport services and infrastructure for non-motorised modes and charging/refuelling of clean vehicles is needed to reduce congestion and emissions. Cities above a certain size should be encouraged to develop Urban Mobility Plans, bringing all those elements together. Urban Mobility Plans should be fully aligned with Integrated Urban Development Plans. An EU-wide framework will be needed in order to make interurban and urban road user charging schemes interoperable."*

These Urban Mobility and Development Plans have to design modern infrastructure containing network of corridors for efficient and optimised freight and passengers' traffic satisfying the requirements for clean fuels and low emissions. The core network must ensure efficient multi-modal links between the EU capitals and other main cities, ports, airports and key land border crossing, as well as other main economic centres. Special attention is given to the scales of these plans, which have to overcome the differences between East and West Europe. Each EU country has to plan the corresponding funds needed for creating a modern and efficient European traffic network.

The use of automation in transport systems

Distributed dynamic routing of a fleet of cybercars

(Renshi Luo, Ton J.J. van den Boom, Bart De Schutter,** Delft Center for Systems and Control, Delft University of Technology**)

In many urban areas, the ever-increasing use of private cars together with the highly disorganized behaviours of human drivers is causing severe problems (e.g., a large amount of injuries and fatalities, frequent congestion, soaring energy consumption and pollution, increased noise levels) that degrade the quality of urban life and the urban environment. Being considered suitable solutions to these problems, public transportation systems (e.g., buses, trams, subways, etc) have been widely used and continuously improved. However, in public transportation systems, passengers have to accept pre-defined schedules and routes, and hence have to spend extra time waiting and transferring, and they also have to travel longer distances because of indirect routes. Since they are outperforming public transportation systems on the personal mobility level, private cars still form a large part of the current transport system and the problems caused by the increasing use of private cars are still largely unsolved.

A new and promising option to deal with this situation is to use a cybernetic transportation system i.e., an intelligent transportation system formed by a fleet of cybercars that drive autonomously and provide on-demand and door-to-door service [1,2]. Cybercars are often small-sized and based on electric power, which is more efficient and less polluting than fossil fuels. They have high flexibility and reactivity (i.e., they can provide on-demand transportation service for any location at any time) and hence offer better urban mobility than conventional public transportation systems [3]. Besides, in terms of energy consumption, they are even competitive on a per passenger-km basis compared with public transportation [4]. The European project CyberCars [5] is one of the first projects dedicated to developing such a cybernetic transportation system.

State of the art

Automated driving technologies have been well developed for individual vehicles [6] and some of the technologies (e.g., adaptive cruise control [7], automated lane change [8], etc.) are operating in real-life. But the lack of efficient strategies for the cooperation of a fleet of cybercars is still one of the biggest obstacles that hinder the large-scale application of cybercars.

The cooperation of a fleet of cybercars is necessary for the optimal performance of a cybernetic transportation system. When it comes to cooperation, cybercars can be characterized as moving decision-making agents with extensive on-board processing and communication capabilities as well as abundant information of the environment.

One essential kind of cooperation among cybercars is dynamic routing. However, so far there are only a few researches [9,10] addressing the dynamic routing problem of vehicles. What is more, those researches either focused on conventional transportation systems with human drivers or Intelligent Highway Systems which have different features from the cybernetic transportation system. Therefore, the methods proposed in those researches are not amenable to cybernetic transportation system.

In fact, the vehicle routing problem of on-demand transportation system has been studied in [11]. However, by representing the road network as a weighted complete graph and defining fixed attributes (travel time, travel cost, etc) for each arc, that paper only solved the problem on a daily basis not based on real-time traffic condition. Therefore, the method proposed by [11] will not work in real-world network since the traffic conditions in urban areas vary during a day due to different transportation service demands at different times, such as at peak hours and off-peak hours.

Challenges

Having discussed the importance of dynamic routing of cybercars to the sound performance of cybernetic transportation system and the inadequacy and unsuitability of the current researches, we find it necessary to address the dynamic vehicle routing problem of cybernetic transportation system by considering the dynamics and the energy consumption of each cybercars according to the real-time conditions of the road network. In our search, we to develop an efficient route choice control strategy for a fleet of cybercars so that their total time spent and total energy consumption throughout the network are minimized.

Prior to the design of the efficient route choice control strategy for cybercars, a reasonably accurate and sufficiently fast model of the dynamics of cybercars that is suited for control design is needed.

So far, the majority of researches in real-time traffic control [10,12,13] have focused on using the macroscopic models such as METANET model to describe the dynamics of traffic flows or platoons of vehicle. However, since we need to take into account every cybercar, we first need a microscopic model to describe the dynamics (such as position, speed, etc) of each cybercar. Further, we also have to model the impact of the dynamic route decisions of cybercars on the states (such as traffic density) of the road network. Therefore, a macroscopic model describing the dynamics of the road network is also highly needed. Summarily, we need to find or develop a flexible model that is capable to describe the microscopic dynamics of each cybercar and the macroscopic dynamics of the whole network.

Assuming we have got a suitable model to describe the cybernetic transportation system, the next question that arises is to how to develop a control strategy that can determine prompt and optimal (both time-optimal and energy-optimal) routes for cybercars, and that can be practically implemented in large-scale urban road network.

Up to now, most control methods are based on a centralized control paradigm and the related theories and technologies have been developed. However, it is not amenable to cybernetic transportation system for reason of scalability, computational complexity, and robustness. More specifically, it is extremely difficult to find every vehicle's current location and destination, information that would apparently be essential to route the vehicles in an optimally coordinated way. Moreover, even if sufficient or even complete information of every vehicle and the network is available, the general problem of determining the optimal routes for vehicles is known to be NP-hard (vary hard to solve), even for static road network, not to mention for dynamic network.

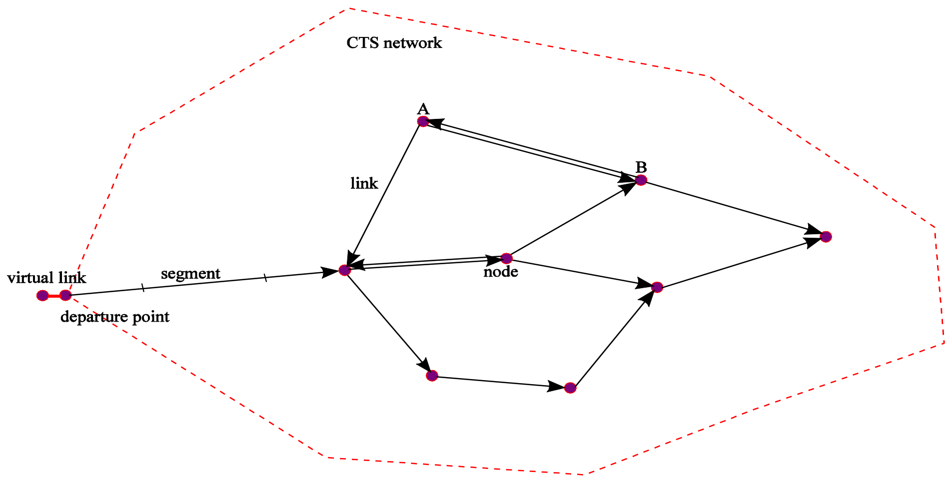
Distributed control approach can overcome the shortcomings of the centralized approach. In a distributed approach, the control problem is divided into many subproblems, with each subproblem being managed by a local controller. The local controller is responsible for solving its local problems. Finally, all the subproblem solutions are combined to yield the overall solution [14]. Although distributed control approach is promising, it does not mean that a distributed approach can definitely solve the dynamic routing problem of cybercars. Actually, due to the discrete nature of the route decision variables and the continuous nature of the dynamics of cybercars and the road network, the cybernetic transportation system will eventually have to be described as a hybrid system. However, there is hardly any research focusing on developing distributed control algorithm for hybrid system so far. That is to say, even if a modeling of cybernetic transportation system that is suited for distributed control design is obtained, we still have to face the challenge of lack of well-developed distributed control algorithm before we can successfully solve the dynamic routing problem of cybercars.

Actions for the community

We consider a cybernetic transportation network consisting of a set of dedicated (i.e., only open to cybercars) roads where vehicles are not allowed to turn around, and a set of dedicated intersections. Each road starts and ends at an intersection. Each cybercar can make its desired route decisions or receive route instructions from routing controllers at any time, but only the route decision or instruction right before the cybercar crosses an intersection will be put into use.

Modeling of the dynamics of cybercars and the network

We simply refer to a road as a `link', an intersection as a `node'. Each link is divided into a number of segments with length typically in the range of 50 to 100 m. The layout of the network can be represented by the following figure.



At any time, the traffic density (i.e., the number of vehicles per kilometer) in a segment is assumed to determine the equilibrium speed of all the cybercars running in that segment. The actual speed of each cybercar is determined by its previous speed and its equilibrium speed. Moreover, each segment has its maximum capacity (i.e., the maximal allowed number of cars at the same time). More specifically, if the number of vehicles running in a segment reaches or exceeds the maximum capacity, that segment will be blocked and no vehicle is allowed to enter that segment. The energy consumption of a car is a function of its velocity and also the variation of its velocity (i.e., acceleration or deceleration).

Distributed model predictive route choice control of cybercar

The route decisions are made by solving a constrained finite horizon optimal control problem in a receding horizon fashion and in distributed way. More specifically, at each control cycle:

divide cybercars into groups or consider every individual cybercar

divide overall control problem into subproblems

- assign subproblems to local agents (group agent or every cybercar)
- with partial information, agents solve local subproblems in a feasibly cooperative way

Theme 3.2: Application Scope and Constraints

3.2.1 Introduction:

The potential scope of applications of ARTS, and the development of a hierarchy of application areas that is amenable to autonomic techniques. Some areas may be considered more naturally amenable to autonomic techniques, such as local and regional control centre planning support, and real time traffic control. Applications such as automated incident detection may be considered as more problematic, as human judgement may always be superior in determining causes for alarm. Other applications, and emerging technological and organisational ideas, such as cooperative and infrastructure systems, vehicle to vehicle enabled traffic support and demand management, need to be investigated from an ARTS standpoint.

Traffic assignment with environmental objectives (by Jorge Bandeira)

Although there have been some improvements over recent years, road transport sector stills contributing significantly to emissions of NO_x (33%), PM_{10} (13%) and CO (27%). People living near congested roads across Europe are still particularly exposed to air pollution. According roadside air monitoring stations data, harmful nitrogen dioxide (NO_2) and Particulate matter concentrations above legal limits were observed at 44 % and 33% of situations in 2010 (EEA, 2012). A more efficient management of existing infrastructures has been identified as a key policy with great potential to reduce emissions. These measures may include behavioural changes in the operation of vehicles (eco-driving) as well as the choice of routes with lower emissions impacts associated. ~~This contribution is~~ A summary of scientific published works on traffic assignment and smart routing strategies with environmental goals follows in 3.2.2.

Development of simulation platforms for environmental (and even social) impacts assessment of transportation policies: future trends (by Tânia Fontes)

The increase in computational speed, the exponential growth of big traffic data, and the possibility of storing these data quickly and cheaply have allowed an increase of the expectations regarding the improvement of efficiency in the use of existing transportation infrastructures. Although the use of complex software applications has grown, they are often used by people without a strong background of model-building. Moreover, these applications are traditionally focus in on impact at time (e.g. travel time, noise, air concentrations). In addition, the synergies between environmental components are usually dismissed and the long data series are usually not available to perform epidemiological modelling studies.

Sofia case study - Noise pollution and traffic control (by Krasimira Stoilova)

The idea of this study is to identify the potential application of noise measurements for accessing the intensity of the transportation flows in urban streets and to apply noise related control policy for the transport flows. The noise measurements are easy to perform which benefit the implementation of technical devices for intelligent transportation systems.

3.2.2 State of the Art and Current Research Directions

TRAFFIC ASSIGNMENT WITH ENVIRONMENTAL OBJECTIVES (***JORGE BANDEIRA***)

Usually drivers take into account two main criteria when they select a specific a route: travel times and travel costs [1]. There is clear evidence that exposure to travel information is related to the higher likelihood of adjusting planned travel [2]. Nagurney & Dong, (2002), argued that it is realistic to assume that a number of drivers could consider an environmental criterion into their decision-making process with the increasing environmental concerns [3]. Using a logit based stochastic user equilibrium (SUE) model under traveler information provision, a study has estimated the marginal cost pricing policy for a certain link from an economic, behavioral, and environmental viewpoints [4]. From an economic perspective Gaker et al. [5], concluded that trip-specific information related with greenhouse gas emissions has considerable potential of increasing sustainable behavior. The authors have quantified the "value of green" at around \$0.50/pound of GHG avoided. Sharma & Mishra [6] highlighted that emission pricing on routes may be implemented ensuring that it does not adversely impact the composite network and the road user's travel costs.

In the last two decades, there has been a growing interest in the effect of route choice in reducing emissions. Table 1 lists the most relevant studies carried out in the field of route choice optimization, taking into account energy and emissions.

In 1993, Tzeng and Chen [17] carried out one of the first studies focusing the relationship between route-choice (or traffic assignment) and air quality. The authors tried to establish the most advantageous flow patterns using three objectives: time, travel distance, and emissions, particularly CO [17]. It should be noted that the developed model takes into assumption a system optimization in which a central controller is able to manage the traffic in a way that is most favorable from a system point of view.

In 1994, Rilett and Benedek [18] have studied the implications of using advanced traffic management system (ATMS) and advanced traffic information systems (ATIS) on traffic networks namely with regard to traffic congestion and other transportation by-products such as noise and air pollution. ATMS could be applied to achieve the environmental goals in either an active or passive way. While in the active method there is a centralized route guidance system (RGS) which informs drivers which routes they must follow, a passive system consist of an electronic toll collection system in which drivers are charged for their amount of emissions generated.. In 1998, the same researchers explored this issue taking into account the advent of ITS [18]. Several methods of traffic assignment were tested on a calibrated network, using several approaches such as user equilibrium (UE) or system optimum (SO). CO emissions optimization was compared with UE and SO based on travel time. The researchers demonstrated that the traffic flows of the SO assignment based on CO emissions condition were roughly equivalent to the flows of the UE and SO conditions within a small error range.

Nagurney et al, (2002) developed a multi-class and multi-criteria traffic network equilibrium model with an environmental criterion. The model was the first considering elastic travel demands in the presence of a permit or license market system, in order to reduce pollution emissions and taking into consideration both compliant and noncompliant behavior. Using a macro scale emission model, Sugawara and Niemeier [9] designed an emission-optimized traffic assignment model using CO emission factors based on average speed. The experimental results showed moderate reduction in system-level vehicle emissions under emissions-optimized trip assignment compared with the conventional time-dependent UE and SO models. The researchers also concluded that the emission optimized assignment is more efficient when the network faces low or moderate levels of congestion.

Ericsson et al. [19] estimated the potential for reducing fuel consumption and CO_2 emissions, by means of a navigation system in which the optimization of route selection is based on the reduction of fuel consumption rather than the conventional shortest time or distance. In 2008, Ahn and Rakha [21], realized that the majority of previous research efforts have applied basic travel time functions and mathematical expressions to compute emissions rates based on average link velocities without considering momentary changes in a vehicle's speed and acceleration. To overcome some of these limitations in evaluating the impact of route choice, the researchers used and compared two microscopic models (CMEM and VT-Micro) and the macroscopic model MOBILE6. The study has demonstrated that macroscopic emission estimation models can generate inaccurate conclusions because the transient vehicle behavior along a route is not considered.

Barth et al. [20] developed an environmentally-friendly navigation system. Firstly, the researchers collected an extensive vehicle activity data (second-by-second position and speed) using GPS-equipped probe vehicles. Then, through the CMEM microscopic model, functional relationships were established between the microscale speed patterns of individual vehicles and macro scale traffic measurements such as average traffic speed, density, and flow. Using these developed relationships between macro and microscale parameters, the system is able to estimate representative speed trajectories for different levels of measured congestion. Network-wide routing algorithms were developed in order to minimize energy consumption and emissions.

Zhang et al. [22] modeled the emission levels in every location of a hypothetical network considering the influence of multiple links on global air quality. In order to consider mutually the travel cost and on-road emissions, the authors employed an additive objective function.

Table 1 Relevant research on the impact of traffic assignment policies in terms of emissions and energy use.

Ref.	**Study location**	**Environmental Goals**	**Emissions Estimation**	**Highlights**
(7)	Virtual	Fuel, CO_2	m (VT-micro)	Savings in fuel consumption of 15 % using the *Integration* model
(8)	Virtual	Generic	NA	Development of a multimodal network eq. model with emission pollution permits
(9)	Virtual	CO	M [f(av speed)]	Development of a trip-assignment model. Emissions savings over the European Union up to 25% %-
(10)	Virtual	CO_2	M [f(av speed)]	Emissions savings (up to 28%) if vehicles are routed taking emissions into account
(11)	Virtual	NO_X, VOC, CO	M [f(av speed)]	When a network is designed for minimal travel time, NO_x and CO emissions can increase
(12)	Virtual	Fuel, CO_2	M [f(av speed)]	Extension of the classical Vehicle Routing Problem (VRP). Significant CO_2 savings.
(13)	Virtual	CO	M [f(av speed)]	CO emission with minimized travel time when drivers take longer routes with low speed profiles
(14)	Virtual	CO_2	m (CMEM adapted)	Macroscopic models can provide inaccurate information to eco-drivers.
(15)	Two OD pairs North Carolina, USA	Fuel, CO_2, NO_X, HC, CO	PEMS & m (VSP)	NO_X savings up to 24% (comparing alternative routes over different periods)

(GUO, HUANG, & SADEK, 2013)	Metropolitan network Greater Buffalo-Niagara, USA	Fuel, CO	m (Moves)	Assessed the impact of market penetration rates eco-routing vehicles on the system-wide
(17)	Urban network Taipei, Taiwan	CO	M (Local survey)	Development of a traffic-assignment method with multiple-objective decision making
(18)	Urban network Ottawa, Canada	CO	M [f(av speed)]	To minimize CO during peak hours, the system travel time may increase 2%
(19)	Urban network Lund, Sweden	Fuel, CO_2	m (VETESS)	8.2% fuel savings by using a fuel-optimized navigation system.
(20)	Highway system Los Angeles CA, USA	Fuel, CO_2, NO_X, HC, CO	m (CMEM)	A time minimization path can minimizes emissions (CO_2 savings up to 42%)
(21)	Arterial and Highway Northern Virginia, USA	Fuel, CO_2, NO_X, HC, CO	M&m (VT-micro, CMEM, Mobile6)	Savings over the European Union condition up to: CO_2 7%, NO_X 15%, HC 44%, CO 50%
(22)	Virtual + Urban network College Station, TX, USA	CO	M (Mobile 6.2)	Potential for reduce emissions concentrations with a marginal increase in travel time
(23)	Arterial and Highway Zoetermeer, Holland	Fuel	m (VT-CPFEM)	A provincial route can offer av. time savings of 25% and fuel savings of 45%
(24)	Aveiro, Oporto (Portugal) Norfolk (Va, USA)	Fuel, CO_2, NO_X, HC, CO	M (VSP)	Trade-off CO2 vs. local pollutants minimization – “eco” routes can cut urban areas
(25)	Corridor Virtual	Fuel, CO_2, NO_X, HC, CO	m(vsp) / others	Eco-traffic management tool
(26)	Metropolitan network Cleveland-Columbus,OH USA	Fuel	m (VT-micro)	When 20% of eco-routing vehicles are assigned on the network, vehicles consume higher fuel levels.

M – Macroscopic, m – microscopic, PEMS – Portable Emissions Measurement System

Then, a genetic algorithm was implemented to solve the complex optimization problems with non-linear terms. The concept of a cell-based was also introduced to model emission concentrations in order to either the average emission, or the maximum emission could be considered in the optimization process. The researchers concluded that the developed optimization model is able to help the reduction of CO emissions concentration in the locations with worst environmental conditions which be accomplished with a minor increase in travel time and average emission concentration. Other authors have focused on minimizing emissions in specific fleets. In 2010, Figliozzi [10] has created a new system (emission vehicle routing problem – EVRP) aiming the minimization of pollutant emissions from commercial vehicles. Here, a heuristic is proposed to decrease the level of emissions. CO_2 emissions are based on a polynomial expression that relates real-world CO_2 emissions and travel speed profiles.

All study’s conclusions pointed out that route choice has a significant impact on emissions and energy use. However, few studies have addressed the effect of rush periods on emissions [30]. The distribution of vehicle speeds and accelerations in traffic diverge by type of road facility and amount of traffic volume, generating large discrepancies in emission levels [31]. Possibly, this fact has contributed to some inconsistency on literature about this issue. On one hand research studies [15,20,32] point out that time minimization paths often also minimize energy use and emissions. On the other hand different work [18,23,33] verified that frequently the faster alternatives are not the best from an environmental perspective

Development of simulation platforms for environmental (and even social) impacts assessment of transportation policies: future trends

As example of the assessment of transportation impacts, Table 2 lists the most relevant studies combining road traffic modelling with emission and/or air quality modelling. About 60% of the studies include only road traffic modelling and emission modelling. The integration of air quality modelling with traffic simulation models was done in only 30% of the studies. Although some studies explains the benefits of integrated some modelling tools (e.g. Borrego et al., 2004), the laborious and time-consuming data preparation work involved is still high. Nevertheless, the use of these tools allows a use more efficient and in a shorter time when compared with the traditional methods generally used by local authorities.

The revision of the literature also shows that the number of studies which use microscopic traffic models to assess environment impacts is significant higher than the other model types (70%). VISSIM and PARAMICS seem to be the most popular microscopic traffic models (42% and 37% respectively). Abou-Senna et al. (2013) explains that these microscopic models provide accurate emission estimations based on a precise and operating mode distributions on a second-by-second basis. Nonetheless, the number of studies linking traffic and air quality models using instantaneous emission models is very limited. In fact, from the analysed studies, only nine studies link, microscopic traffic model with an air quality model. From these, seven studies apply average speed emission models (Bandeira et al., 2011; Borrego et al., 2004; Dias et al., 2014; Gulliver and Bridges 2005; Mensink and Cosemans 2008; Mumovic et al., 2006; Namdeo et al., 2002) and two uses instantaneous emission models (Amirjamshidi et al., 2013; Misra et al., 2013). Therefore, these numbers, suggest that the potential of these new models is yet a subject poorly explored.

In summary, it can be observed that the use of instantaneous emission models to link both road traffic and air quality models has not been well addressed in the literature. This can be explained by the fact that atmospheric road impacts are only analysed at emissions level. However, this is an incomplete approach of the problem due to the important role of meteorology and land use.

Table 2. Studies which include integrate platforms of road traffic, emission and air quality models

Reference	Models																	
	Road traffic								**Road emission**								**Air quality**	
	Microscopic				Mesos-copic	Macroscopic			Instantaneous					Average speed			Local	Urban
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8		
Abou-Senna et al., (2013)	■										■							
Amirjamshidi et al., (2013)				r_1								■						a_1
Bandeira et al., (2011)								r_2						■				a_2
Boriboonsomsin and Barth, (2008)		■										■						
Borrego et al., (2004)					■		■							■			a_3	
Chen and Yu (2007)	■											■						
Csikós and Varga, (2012)	■									■					■			
Dias et al., (2014)	■													■				a_4
Fontes et al., (2013)	■								■						■			
Gulliver and Bridges (2005)						■										e_1		a_5
Jie et al., (2013)	■									■								
Lin et al., (2011)					■						■							
Madireddy et al., (2011)		■								■								
Mandavilli et al (2008)			■										e_2					
Mensink and Cosemans (2008)		■														e_3	a_6	a_7
Misra et al., (2013)		■										■					a_8	a_9
Mumovic et al., (2006)						■										e_4	a_{10}	
Namdeo et al., (2002)						■										e_5		a_5
Nejadkoorki et al., (2008)						■										e_6		
Nesamani et al., (2007)		■											e_7					
Noland and Quddus (2006)	■											■						
Panis et al., (2006)				r_3									e_8					
Sidere t al., (2013)							■									e_9		
Xie et al., (2012)		■									■							
Zegeye et al., (2013)								■								e_{10}		
Zhao and Sadek (2013)		■									■							
Zhang et al., (2009)	■								■									
Zhang et al., (2013)			■								■							

Notes:

Road models: 1: VISSIM; 2: PARAMICS; 3: aaSIDRA; 4: Other models; 5: DinusT; 6: SATURN; 7: VISSUM; 8:METANET. r_1: METANET; r_3: TRANUS; r_3: DRACULA.

Emission models: 1: VSP; 2: Versit+Micro; 3: MOVES; 4: CMEM; 5: Other models; 6: TREM; 7: COPERT/CORINAIR; 8: Other models. e_1: SATURN; e_2: SIDRA; e_3: MIMOSA (derived from COPERT II); e_4: EFT; e_5: ROADFAC; e_6: Lu et al. (2002); e_7: MOBILE; e_8: Panis et al., (2006); e_9: VT-micro; e_{10}: MOVES.

Air quality models: a_1: gaussian plume model; a_2: TAPM; a_3: VADIS; a_4: URBAIR; a_5: ADMS; a_6: OSPM; a_7: ISCST3; a_8: AERMOD; a_9: QUIC a_{10}: PHOENICS.

Traffic assignment with environmental objectives

Despite the positive results in terms of potential for emissions reduction based on an appropriate route choice and innovative traffic management techniques a number of important trade-offs that should be addressed in further research.

i) Fuel consumption and CO2 vs. local pollutants.

This conflict would be more problematic in regions where higher concentrations of local pollutants such as CO are usually observed. However, this conflict could be reduced with an increasing market penetration of cleaner vehicles. Thus, the contribution of the transportation sector to local pollutants emissions will be reduced considerably in the medium term. Additionally local pollutants emissions can be reduced by applying speed management/harmonization techniques on motorways aiming at reducing higher speeds and consequent high emissions levels.

ii) Eco-friendly route vs. travel time

Considering an eco-indicator for route choice based on economic cost of each pollutant, it was found that generally, the selection of an eco-friendly route leads to higher travel time. This fact could seriously limit the acceptance of eco-routing suggestions to a considerable number of drivers. However, if the eco-routing strategy is predominantly focused on CO2, this conflict would tend to decrease.

iii) Eco-friendly route vs. local impacts

In some circumstances the routes that yield a minimization of pollutants cross densely populated areas. This fact suggests that a careful assessment of potential externalities that may arise from a purely dedicated navigation system based on the minimization of total emissions is needed.

iv) Eco-friendly route vs. Vehicle type

Depending on the characteristics of the routes linking a certain OD pair, the eco-friendly route may differ according to the type of vehicle. For individual navigation devices, this issue can be easily resolved, by including specific information on different types of vehicle into routing algorithms. For a centralized network management, the average fleet composition must be considered in order to maximize the effectiveness of advanced traffic management systems.

v) The price of "green anarchy"

The degradation in network performance caused by the self-interested behaviour of network users is being studied over the last decades by a considerable number of researchers. The Price of Anarchy (term introduced by Koutsoupias and Papadimitrio [38]) measures the ratio between average travel time under system optimum (centralized) and user equilibrium (decentralized system). Research has been demonstrated that the deterioration of the network performance may be even more notorious when drivers are routed to reduce their individual environmental impacts.

~~***Development of simulation platforms for environmental (and even social) impacts assessment of transportation policies: future trends***~~

Modelling frameworks

To fulfilling a sustainable transportation policy goals, automatic integrated simulation tools must be developed to assess the environmental impacts (or even social impacts) of traffic. In the case of emissions, hot, cold and evaporative emissions must be studied, considering a dynamic environment (e.g. the variability of air temperature). Different atmospheric gases (e.g. PM, NO_X, CO, HC) must be analysed considering the effects of land use and meteorology.

These new integrated models should considerer different spatial and temporal levels of application. At local and urban level, particular focus must be done in the automatic integration of detailed data (e.g. from GPS or road infrastructures) considering the definition of standard communication protocols. These new high potential models should integrate background world maps, in order to help users. Figure 4 shows an example of integration platforms using different model types.

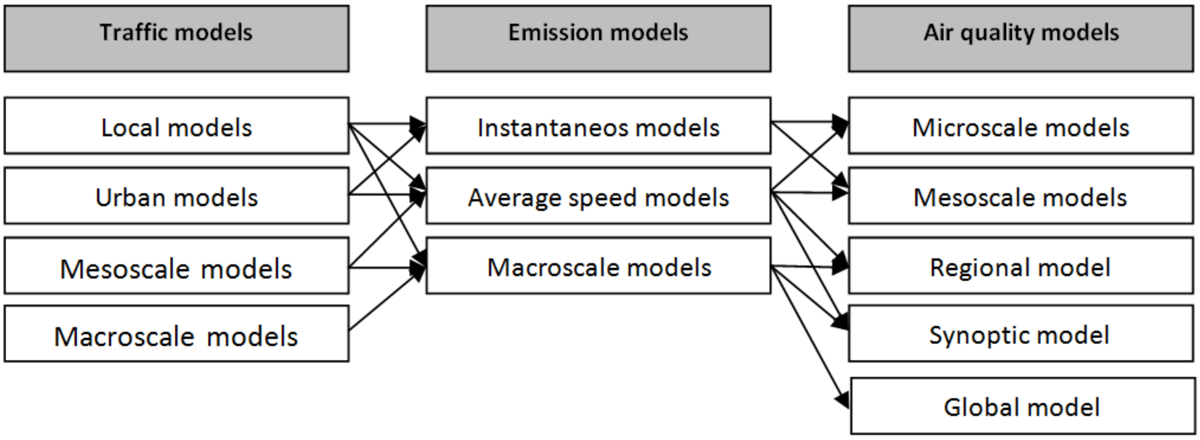


Figure 4. Example of integration platforms of road traffic, emission and air quality models

In order to show some examples of applications to assess the impact of road traffic on air quality, next sections will present two different cases studies: an integration methodology based in the assessement of the impacts of road transportation in an urban domain and another based for a mesoscale domain. In each case study, the general procedure is presented showing the calibration and validation steps. For each model, the main inputs and outputs are also presented. For each case study several pollutants can be study, as carbon monoxide (CO), nitrogen oxides (NO_x), Volatile Organic Compounds (VOC) including methane, carbon dioxide (CO_2), sulphur dioxide (SO_2) and particulate matter with aerodynamic diameter less than or equal to 10 mm (PM10).

Case study 1: urban area

Figure 5 shows the main steps of the integrated methodology to assess the impact of road traffic on air quality and an urban area. Firstly, data related with road configuration, vehicle dynamics collected using GPS data-logger equipped vehicles must be used to validate traffic volumes estimated by a microscale road traffic model (e.g. VISSIM). The outputs of this model can be used as inputs in an emission average speed model (e.g TREM) to quantify the emission amounts with high temporal and spatial resolution. Finally a microscale air quality model (e.g. URBAIR)) must be applied to evaluate the urban air quality. Next sections present the main details of each of these steps.

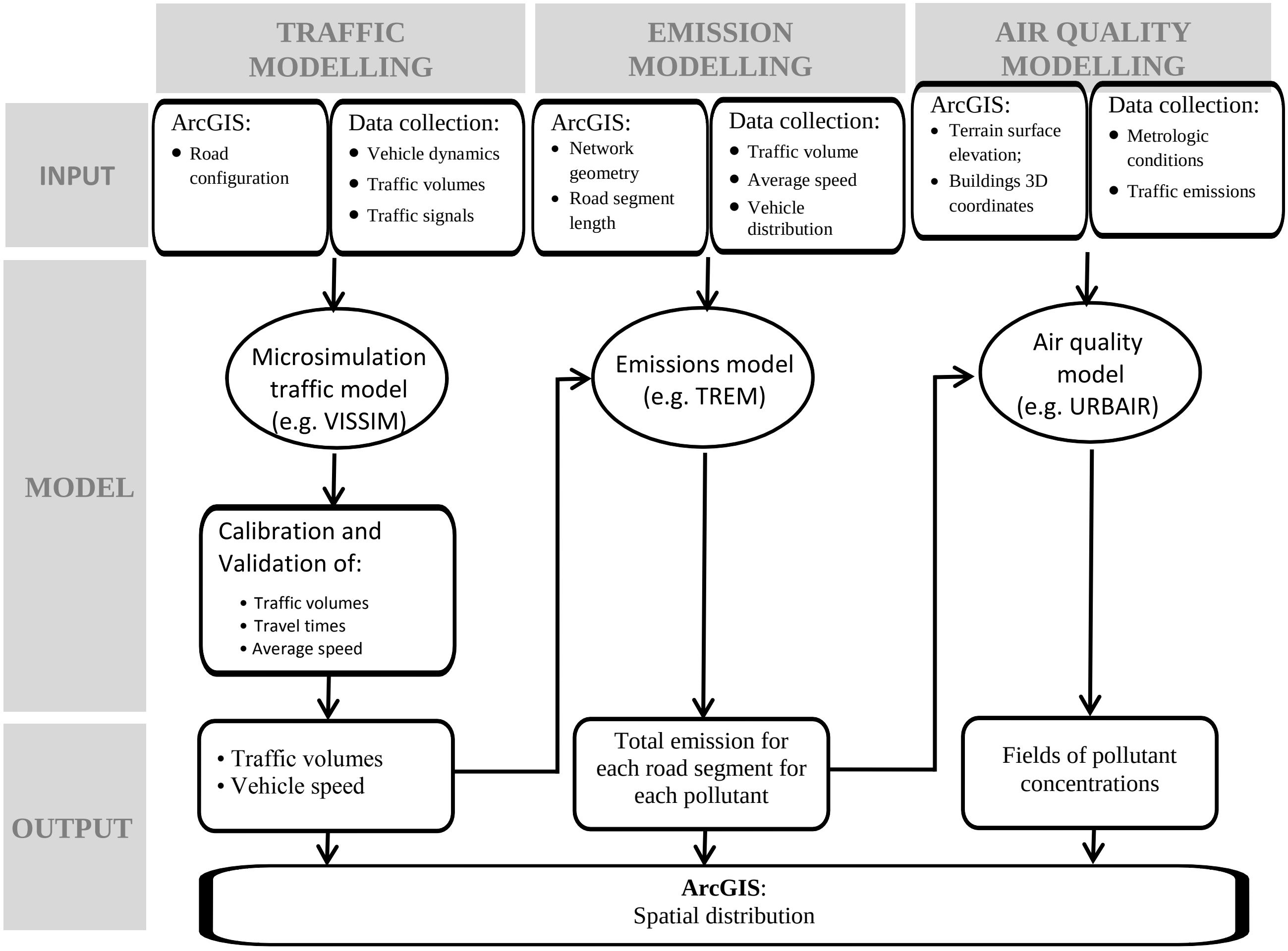


Fig. 5. Methodological simulation framework for an urban domain.

Transportation modelling: VISSIM model

VISSIM 5.30 model can be applied to simulate individual vehicle movements during peak or non-peak periods. With this model can be defined different road-user behaviour parameters, different vehicle types and traffic controls. Furthermore, it allows different vehicles performance such as desired maximum braking and acceleration per vehicle and class (PTV, 2011). Previous studies have documented the effective use of this traffic model in assessing management strategies in real world case studies (Fontes et al, 2014; Mahmod et al., 2010).

To model the urban network, field tests must be conducted to collect vehicle dynamics, traffic volumes and traffic signals timing during representative periods of time. In order to reduce systematic errors, the tests must be performed using different drivers and vehicles.

The model evaluation should be made in two main phases: calibration and validation. Calibration and validation must be based on different datasets. The calibration addressed the parameters related to the number of simulation runs, driver behaviour parameters (car-following and lane-change parameters) and desired speed distributions. This step consists of fitting above traffic model parameters according to the study domain characteristics. The validation step must be focused on the comparison between field data parameters and traffic model outputs. The validated parameters must include: a) traffic volumes; b) travel times and c) average speed. To obtain an accurate representation of network traffic conditions, two goodness of fit measures can be used: 1) Geoffrey E. Havers (GEH); and 2) Root Mean Square Error (RMSE). The GEH compare observed and estimated traffic volumes (Dowling et al., 2004) while RMSE quantifies the average magnitude of the error (Cambridge Systematics Inc, 2010).

Emissions modelling: TREM model

The Transport Emission Model for Line Sources (TREM) can be used to estimate pollutant emissions released to the atmosphere by road traffic. TREM was firstly developed on the basis of COST319/MEET approach and focused on CO, NO_x, VOC including methane, CO_2, sulphur dioxide (SO_2) and PM_{10} (Tchepel 2003; Borrego et al., 2003, 2004; Martins et al., 2009; Bandeira et al., 2011). Also, a new module to calculate the emissions of traffic-related hazardous air pollutants was included in this model (Tchepel at al., 2011). Moreover, to improve conversion of the resulting emission data to the format required by air quality models, TREM is linked to GIS (Borrego et al. 2004).

The TREM model is based on emission factors estimated according to average speed and vehicle class (based on engine age, type, and capacity, vehicle weight, fuel type, and emission reduction technology) using the approach for the emission factors implemented in the European guidelines (EMEP/EEA 2013), but with an implementation conceptually different. Road emissions are estimated for each road segment considering detailed information on traffic flux. Thus, the inputs data required by the model are: (i) the road network spatial data; (ii) statistical information on fleet composition; and (iii) traffic volume and vehicle speed for each road segment.

The total emission of the pollutant p (E_p) for each road segment is estimated by the model as follow:

$$E_p=\Sigma(e_{ip}(v).N_i).L \qquad (1)$$

where $e_{ip}(v)$ is the emission factor ($g.km^{-1}$) for pollutant p and vehicle class i defined as a function of average speed v ($km.h^{-1}$); N_i is the number of vehicles of class i and L is the road segment length (km). Emission factor depends on fuel type, engine capacity and emission reduction technology. Therefore, the model output contains the emission rate for each road segment with a temporal resolution identical to the input information on traffic volume.

Air quality modelling: URBAIR model

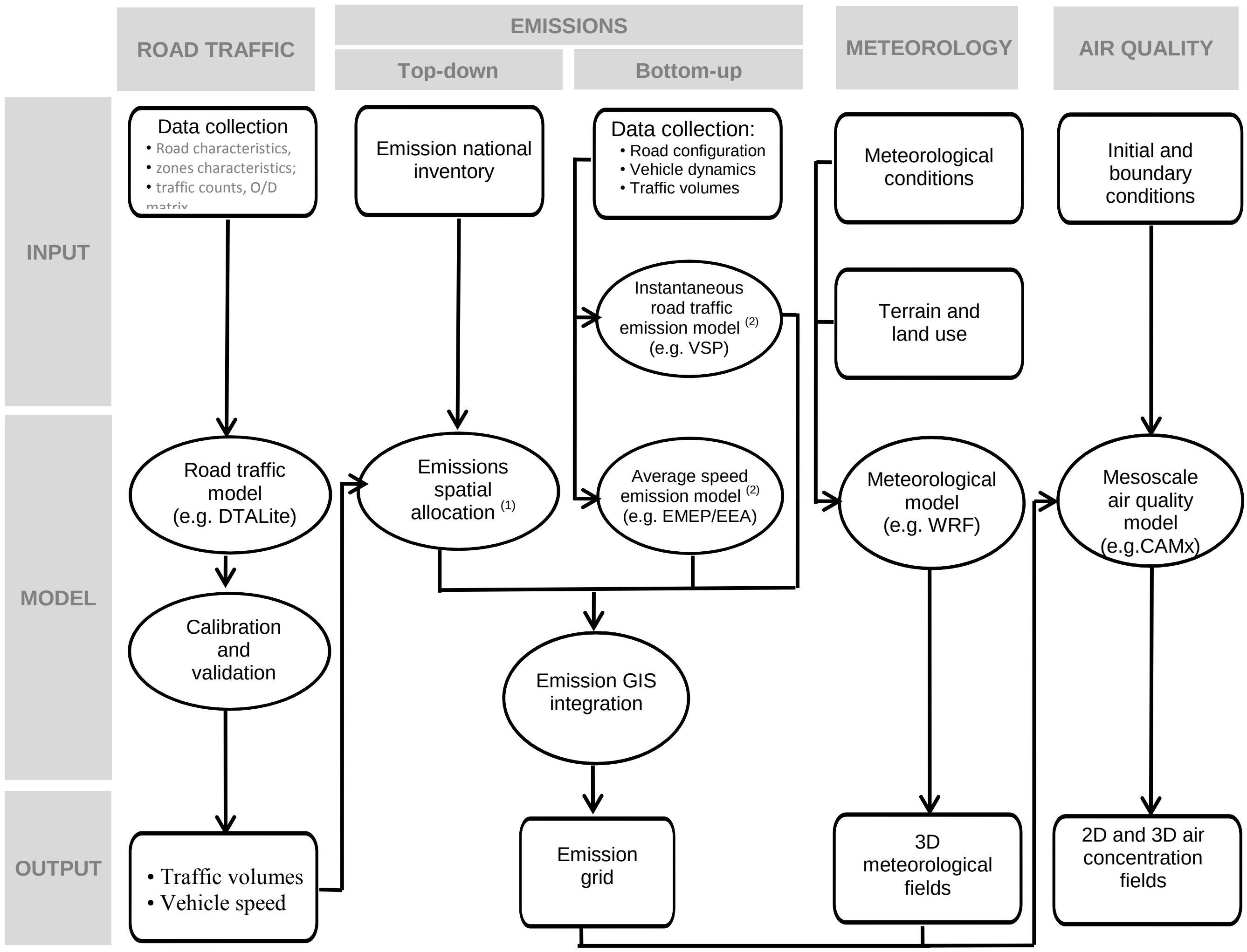
Urban road traffic air concentrations can be obtained by applying the URBAIR model (Borrego et al., 2011). This air quality model provides concentrations patterns for a given spatial domain (with up to about 50 km from the domain centre) and time period (e.g. hourly, daily or one year, in compliance with Directive 2008/50/EC) for different air pollutants, namely: CO, NO_2, SO_2 and PM_{10}.

URBAIR is an advanced Gaussian model, which has been enhanced with a number of functionalities, in particular the treatment of road traffic emissions and 3D urban elements.

This model includes the pre-processing of land use and urban elements geometry, meteorological conditions and air pollutant emissions, coupled with a dispersion module. As input meteorological conditions, such as wind direction and wind speed, and air concentrations measured at one monitoring station located in the domain must be used. Additionally, emissions from the TREM model must be used. To pre-processing the geographic/geometric characteristics of the study domain, which is usually complex and time-consuming, a GIS platform can be used.

Case study 2: mesoscale domain

Figure 6 shows the main steps of the methodology applied for air quality modelling for a mesoscale domain. In the first step the road traffic model DTALite was used. Then, the emissions and meteorological models are used to provide inputs required by the air quality model (e.g. EMEP/EEA). All the emissions from the different activity sectors must be considered to correctly assess the impact of road traffic. The meteorological model requires the topography, land use and land-water masks datasets to produce 3D meteorological fields (e.g. temperature, wind speed and direction, etc.). The meteorological and the emission outputs, as well as the initial and boundary conditions, are used as input in an air quality model (e.g. CAMx). In the following sections an example of road traffic, emission and the air quality models used to estimate the impact of traffic emissions in a mesoscale domain are presented. In these sections the main parameters used to assess the model performance are also described.



NOTES:

(1) Using total emission with NUT IV (municipalities) resolution for: combustion in energy and transformation industries (SNAP 1); commercial and residential combustion (SNAP 2); industrial combustion (SNAP 3); production processes (SNAP 4); extraction and distribution of fossil fuels and geothermal energy (SNAP 5); solvent and other product use (SNAP 6); road transport (SNAP 7); other mobile sources and machinery (SNAP 8); waste treatment and disposal (SNAP 9); agriculture (SNAP 10); and other sources and sinks (SNAP 11).

(2) Estimated for the main roads of the study domain (SNAP 7).

Figure 6 - Methodology to assess the use of different emission models on air quality for a mesoscale domain

Road traffic modelling: DTALite model

To simulate the road traffic of a region the DTALite mesoscopic model can be used (Zhou 2014b). This is a dynamic traffic assignment (DTA) model that requires only a minimum set of static data as input values and some time-dependent values (Origin/Destination - O/D matrix). As a flow model, DTALite uses Newell´s simplified kinematic wave model which defines a triangular relationship between flow and density. With this relationship the model represents the evolution of the traffic, ensuring a direct connection between travel time and congestion. The model relates congestion with physical variables (density, speed, volume) on the links when presented with interruptions in traffic circulation.

The main goal of these DTA models is to determine the flow of traffic and the conditions that result due to interactions of the demand that depends on driver's route selection. In DTALite after inserting an O/D matrix, the simulator builds travel times along the links. Then,

all paths are processed and adjusted according to the information received by the drivers. For this purpose, the definition of zones is a key step to understanding mobility.
The study domain must have a O/D matrices witch can be adjusted to match observed traffic data using the Origin Destination Matrix Estimation (ODME), a routine included in DTALite (2013). This iterative procedure consists in the following steps. First, vehicles are assigned to the network. Second, it compares observed and estimated traffic flows on links with available data. Third, it adjusts demand data. Fourth, it reassigns trips in the next iteration process (Nevers et al. 2013). To do this, ODME uses an empirical function to compare the deviations between observed and estimated data for each link of the O/D matrices and re-calculate a new O/D matrix when estimated data is closed to the observed data. This function is defined by (Zhou, 2013):

$$minL = \sum_{l}\left[\sum_{i,j}\left(P_{l,(ij)} * d_{(ij)}\right) - c'\right]^2 + \sum_{l,s}\left[\sum_{i,j}\left(P_{l,s,(ij)} * d_{(ij)}\right) - c'_{l,s}\right]^2 + \left[d_{(ij)} - d'_{(ij)}\right]^2 \quad (1)$$

where l, s is the link index in a transportation network; $P_{l,(ij)}$ is the link flow proportion matrix which describes the fraction of vehicular demand flow from O/D pair (i, j) contributing to the flow on link l; $P_{l,s,(ij)}$ is the movement flow proportion matrix which describes the fraction of vehicular demand flow from O/D pair (i, j) contributing to the movement counts from link l to link s; $d_{(ij)}$ describes de O/D demand matrix; $d'_{(ij)}$ is the target or historical O/D demand matrix; c' is the link counts; and $c'_{l,s}$ the turning movement counts.

For traffic data collection, representatitive field campaigns must be performed. To estimate traffic volumes and the fleet composition in the field domain, traffic counts must be carried out in different points and periods of the day. Additionally, data to represent the vehicle characteristics such as the fuel type, age and gross weight distribution must be used.

The model calibration can be addressed analysing the parameters related to the O/D matrices data, number of simulation runs and traveller-specific value of time parameter (Zhou 2014b) while the validation step can be focused on the comparison between observed and estimated data for traffic flows and travel times (Dowling et al. 2004). Calibration and validation must be based on different data collection points.

The calibration step consisted of fitting above traffic model parameters according to the study domain characteristics. To verify the performance of the ODME estimation problem, the overall goodness of fit measure (R-squared) for the assigned traffic flows can be used by applying a linear regression Regarding the number of simulation runs, a wide range of guidelines to recommend multiple runs with different random seeds for microscopic models is available. Hale (1997), for instance, suggested an initial number of simulation runs between 10 and 20.

To validate traffic flows, the current accepted practice, as recommended by the Federal Highway Administration (FHWA) (Dowling et al. 2004), is to rely the Geoffrey E. Havers (GEH) statistic for assessing goodness of fit. To obtain an accurate representation of network traffic conditions, some authors (e.g. Casas et al. 2011; Ben-Akiva et al. 2012) recommend that over 85% of selected loop detectors achieve GEH values under 5, but GEH values under 10 are acceptable. Along the use of GEH, the Percent Root Mean Squared Error (%RMSE) and the overall goodness of fit measure (R-squared) for the assigned total volumes (as made in the calibration process) can be used. The %RMSE is a measure of accuracy of the traffic assignment which quantifies the average error between the observed and estimated traffic volumes (Cambridge Systematics Inc. 2010).

Emissions modelling

Emissions can be estimated integrating the emissions from a top-down approach with emissions from the bottom-up approach. Emissions obtained from bottom-up approach provide detailed information on spatial variability of the data. However, their use in air quality modelling is limited due to incompleteness of emission data since there is a significant lack of source-specific information. On the other hand, top-down methodology may provide better overview on the data in terms of total emissions but their spatial allocation is an important source of uncertainty. In this context, a harmonized methodology must be developed in order to integrate both.

The top-down methodology can be applied to disaggregate the anthropogenic emissions, using the national emission inventory (e.g. INERPA). These inventories provides quantitative information for the main atmospheric pollutants: CO, CH_4, NO_x, nitrous oxide (N_2O), SO_x, non-methane volatile organic compounds (NMVOC), ammonia (NH_3), PM10 and PM2.5. The total national emissions with NUT IV (municipalities) resolution are reported for different activities. Besides the activity type classification, two types of emission sources are distinguished in the inventory: large point sources and area sources. Using the top-down methodology, the annual national emissions from anthropogenic area sources for each pollutant and activity sector are spatially disaggregated from the municipality level to the spatial resolution required for the simulation domain.

The bottom-up approach must be used to estimate the road traffic emissions. For this purpose the VSP and/or the EMEP/EEA methodologies can be applied to estimate the PM, NO_x, CO and HC emissions. To apply the VSP methodology, detailed information about vehicle's operation and vehicle's dynamics (second-by-second speed, acceleration and road grade) is required. Because of its direct physical interpretation and strong statistical correlations with vehicle emissions, VSP has become a widely recognized approach for emission modelling from both gasoline (Frey et al., 2008; USEPA, 2002) and diesel (Coelho et al., 2009) passenger cars, as well as to buses (Haibo et al., 2006). VSP values are usually categorized in 14 modes so that each mode generates an average emission rate. Both emissions rates and the VSP equation variable can be found elsewhere (Coelho et al., 2009; Frey et al., 2008; Haibo et al., 2006; USEPA, 2002). Emissions can be derived based on the time spent in each VSP mode multiplied by its respective emission factor (Frey et al., 2008; USEPA, 2002). In the EMEP/EEA methodology (EEA, 2013) the emission factors depend on the speed, age and engine size or tonnage of each vehicle category. Such methodology is based on average speed values.

Air quality modelling

In order to evaluate air quality over the selected study domain, a mesoscale air quality modelling system WRF/CAMx can be applied. The Weather Research and Forecasting model (WRF) is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. A detailed description of this model can be found on Skamarock et al. (2008). The Comprehensive Air quality Model (CAMx) is an Eulerian photochemical dispersion model that considers the emission, dispersion, chemical reaction, and removal of pollutants in the troposphere by solving the pollutant continuity equation for each chemical species on a system of nested three-dimensional grids (Morris et al., 2004). The inputs required by CAMx include air pollutants emissions, initial and boundary conditions and meteorological fields provided by the meteorological model.

The vertical structure of the WRF model includes 27 layers covering the whole troposphere. Topography, land use and land-water masks datasets can be interpolated with the appropriate spatial resolution considering each domain. The WRF simulations can be driven by the ECMWF global analysis with 1° x 1° spatial resolution and temporal resolution of 6 h for surface and pressure levels.

CAMx vertical structure includes 15 layers and in terms of chemical mechanism, the gas-phase photochemistry can be resolved through the Carbon Bond (CB4) (Gery et al., 1989) and the model also contains detailed algorithms for the relevant processes, including aqueous chemistry (RADM-AQ), inorganic aerosol thermodynamics/partitioning (ISORROPIA), and secondary organic aerosol formation/partitioning (SOAP). Initial and boundary conditions for both gases and particulate species can be, respectively, driven by the LMDZ-INCA global model (Hauglustaine et al., 2004) (for CO, PAN and O_3) and the GOCART global model (Ginoux et al., 2001) (for particulate sulfate (PSO4), sodium (PNa) and chloride (PCl)). This approach was tested and used in previous air quality modelling applications (Bessagnet et al., 2004; Ferreira et al., 2012; Monteiro et al., 2007).

For the meteorological simulation the two-way nesting technique can be used in the WRF model. CAMx must be applied for the domains with high spatial resolution.

<u>Case study - Noise pollution and traffic control</u>

This study targets the application of acoustic noise level as state variable for traffic optimization problem. Thus evaluation and implementation of the green light duration of a crossroad section will be performed in respect to noise levels, generated by transport flows.

The problem of controlling the traffic lights is considered as a necessary step for the dynamical traffic flow control [1, 21]. The optimal duration of the traffic lights is done by means of minimization of the queue length at oversaturated traffic junction [3, 12, 13]. The queue lengths are state variables which have to be minimized according to the optimal time duration of the green light. The variables which have to be measured are the density of the input stream (vehicles per hour) and the initial queue length (vehicles) at the intersection. The traffic flow measurements are performed by inductive loops [19, 25] situated closed to

the junction. More sophisticated and expensive way is to implement image processing and software identification tools for real time automatic flow measurements [27].
To obtain the intensity of the input traffic and to evaluate the initial queue lengths in front of the junction is a problem connected with technical support and estimation procedures for assessing different control parameters. Here the equivalent noise level is introduced as a state variable and its initial values can be measured and import in the optimization problem. Due to the direct introduction of environmental parameter in an optimization problem, such control policy will follow optimal policy for the duration of the traffic lights and as a consequence the arterial traffic noise level will decrease its intensity. Thus environmental benefits will result additionally to the traffic optimization.
This study tries to develop a formal model between the intensity of the noise levels and the duration of the green lights on the crossroad section. The control variable is chosen to be the split of the green lights towards the duration of the cycle of the traffic lights. The optimization problem gives as solution the split of the green lights targeting the minimization of the equivalent noise level, originated by the traffic network. The resulting optimal control decreases both the vehicle queues at the crossroads and the noise pollution.

The traffic noise is continuously fluctuating but for a short period of time by integration its intensity this integral value tends to a constant value. For a straight section of road the equivalent (integral) noise level L_{eq} due to the passing series of vehicles over a period of time [t_1 t_2] is given by the integral [20, 4]

$$L_{eq} = 10log\frac{1}{t_2-t_1}\int_{t_1}^{t_2} Q\frac{p_i^2(t)}{p_0^2}dt \tag{1}$$

where Q is the number of vehicles which passed this road section for the time period (t_2- t_1) ; $p()$ and p_0 are the acoustic and the reference pressure levels. If the traffic is steady which means that the average value of vehicles are relatively constant, L_{eq} is no longer dependent on the duration of the measurements so the relation (1) tends to the integral form [28]:

$$L_{eq} = L_{eqi} + 10 \log Q, L_{eqi} = 43 \text{ dB}. \tag{2}$$

The equivalent noise level L_{eq} resulting from a set of several noise sources L_{eqi}, i=1, n, is evaluated as a logarithmic function of the different noise components L_{eqi} [28], or

$$L_{eq}L_{eq} = 10\log\sum_{i=1}^{n}10^{0.1L_{eqi}}$$

(3)

The paper uses these two relations, which come from physical considerations to apply them for the definition of an analytically defined optimization problem. For isolated traffic crossroad section the scheme for performing noise measurements is according to fig.7. Two measurement points A and B are defined, which will assess the incoming traffic stream related with the queue lengths in front of the traffic lights of the traffic junction.
The points A and C are situated distantly and they estimate the intensities of the upstream flows. Points B and D are close to the junction and estimate the noise of the waiting vehicles in the queues.

For this measurement scheme two noise equilibrium equations can be derived for points B and D. It is assumed that the noise levels have been measured on equal distances *d* from the road sections. The noise equilibrium at point B is generated by three main noise sources from:

– the vehicle queue in front of the traffic lights, waiting for green signal, $L^B_{eq=}L_1$;

the noise from the upstream traffic $L^A_{eq} = L_1$c;

- the downstream traffic will decrease the queue length $L^A_{eq} = L_1$c;

– during the green light on section B, L_{out} .

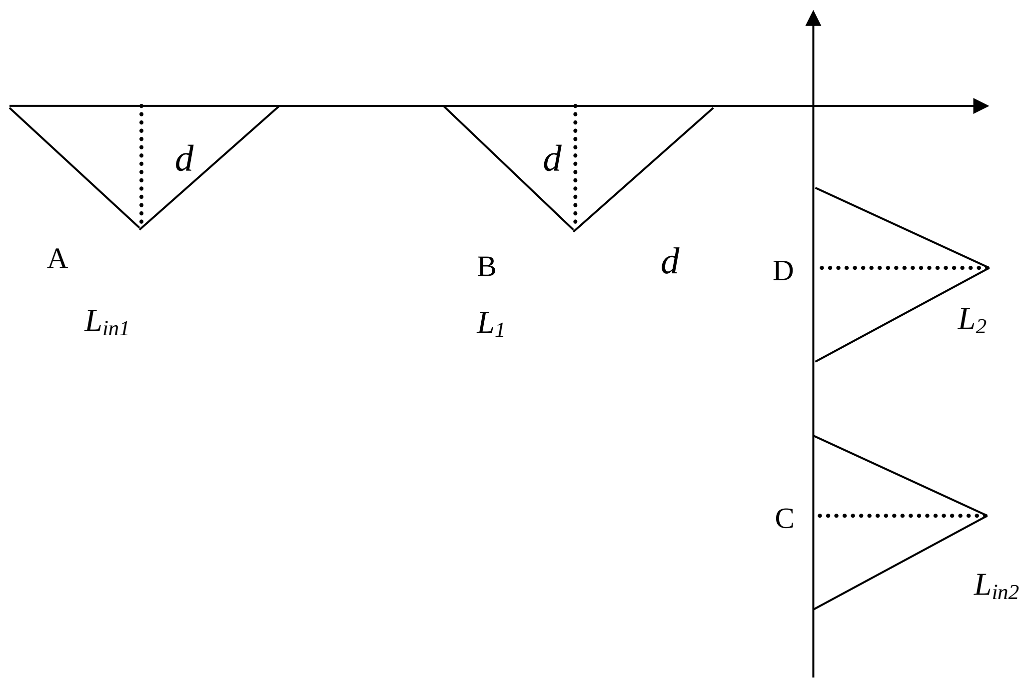


Fig.7. Noise measurements for isolated crossroad section

The integral value of the noise level, resulting at B has to consider these three independent noise sources. Following relation (3), the resulting integral equivalent nose level can be expressed analytically as:

$$L_1\,(k+1) = 10\log[\,10^{0{,}1L_1(k)} + \,10^{0{,}1L_{in1}(k)} - \,10^{0{,}1L_{out}(k)}],$$

where k notate the discrete time for measurements or control purposes.

The value of the downstream flow L_{out} can be expressed by (1) as

$$L_{out} = \,L_{eqi} + 10\log Q$$

The value Q means the number of vehicles which will pass through the intersection during the green signal and it is proportional to the duration of the green light

$$Q(k) = s_1 u(k),$$

where s_1 is the maximum number of vehicles which pass the intersection in horizontal direction during one cycle *c* of the traffic lights; *u*(*k*) is the relative duration of the green light expressed as a part from the total cycle *c*

$$c = \bar{u}_{green} + \bar{u}_{red} + \bar{u}_{amber} \tag{4}$$

$$u = \bar{u}_{green}/c \ ,$$

$\bar{u}()$ - the absolute duration of the traffic signal.

After substitution of the relation L_{out} in $L_1(k+1)$ the noise equilibrium at point B is analytically defined by the relation

$$L_1(k+1) = 10\log[10^{0.1L_1(k)} + 10^{0.1L_{in1}(k)} - 10^{(0.1(L_{eqi}+10logs_1u(k))}] \tag{5}$$

Similar considerations derive the noise equilibrium at point *D* for the vertical direction of the intersection:

$$L_2(k+1) = 10\log[10^{0.1L_2(k)} + 10^{0.1L_{in2}(k)} - 10^{0,1(L_{eqi}+10\log s_2(0,9-u(k))}] \tag{6}$$

where $L_2()$ is the integral equivalent noise level for point *D* at two time discrete moments *k* and *k*+1; L_{in2} is the noise, resulting from the upstream flow for the vertical axis, s_2 the maximum number of vehicles which can leave the junction for one cycle in a vertical direction, 0.9 -*u* is the green light duration assuming that the amber light is 0.1*c* in the cycle (4).

Both relations (5) and (6) are used for the definition of an optimization problem, which physical interpretation is to minimize the integral noise behavior of the junction, taking into account the noise sources from the horizontal and vertical axis. The analytical description of the goal function J_1 has engineering meaning of equivalent noise level arising from the two noise sources at points *B* and *D*. Thus, the minimization of J_1 will get a desirable reduction of the noise behavior of the junction by changing the green lights on the intersection. Common considerations of the optimization theory suggest the components of J_1 to be chosen in a quadratic form, by means to reduce the computational complexity of the optimization problem. Thus the analytical description of J_1 results to the expression

$$J_1 = 10log\sum_{k=1}^{k_p}[(10^{0.1L_1(k+1)})^2 + (10^{0.1L_2(k+1)})^2 + (u(k))^2] \tag{7}$$

The extreme point *u** is evaluated from the first derivative of J_1

$$min J_1(u) => u^* = \arg[\ dJ_1\ /du\ = 0]$$

or

$$u^* = \frac{\alpha s_1 + \beta s_2}{s_1^2 + s_2^2 + 1} \tag{8}$$

The solution (8) is obtained in an analytical form which allows performing closed loop control of the traffic signals in real time. The input data for the control law (8) are the current values of the noise levels $L_1(0)$, $L_2(0)$, L_{in1} and L_{in2}. During the cycle c these values are measured continuously. In the end of the cycle the mean values of $L_1(0)$, $L_2(0)$, L_{in1} and L_{in2}. are substituted in (8) and the optimal duration u^* is applied for the next cycle of the traffic signals. This control policy evaluates permanently the green signal for every traffic cycle.

Noise modelling of arterial street with intersections

The noise equilibrium model is extended for joint connected intersections with an arterial direction. Two junctions of a main street constitute a traffic network which endures prolonged congestions in the downtown of Sofia. The oversaturated traffic network consists of two neighbour junctions with estimated traffic loads given in Fig.8.

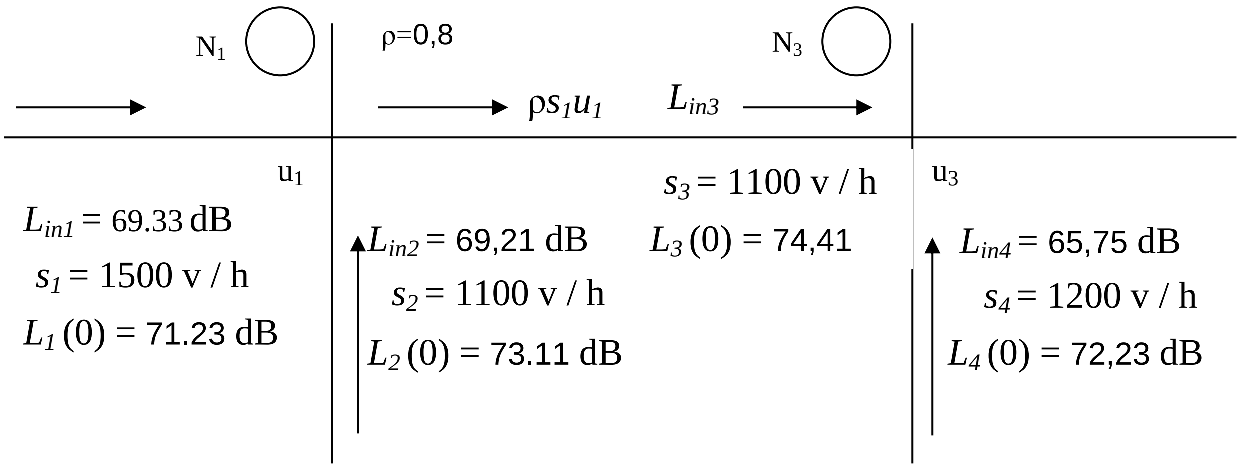


Fig.8. Traffic network scheme

The traffic control of this network must assure smooth traffic motion from left to right direction without raising the vehicle queues in front of the two junctions despite the interruptions done by the traffic signals allowing the vertical traffic flows. The main traffic load arises from the vehicles passing through the horizontal axis, starting from intersection N_1 and continuing to intersection N_3. This occasion gives reason to assume that the input traffic flow for intersection N_3 is constituted by the volumes $s_1 \times u_1$, where the coefficient $\rho = 0.9$ is determined by statistical considerations.

The noise equilibrium model (5) is applied for the case of arterially connected intersections. The control arguments are the relative green durations u_1 and u_3, respectively for both intersections. The estimation of the feasible areas of variation for the controls u_1 and u_3 is performed as follows:

For the intersection $N1$ the input traffic density of the horizontal axis must be less than the downstream flow during the green phase of the traffic signals. This requirement is reworked for the case of noise equilibrium, which will give the minimal duration of the green light u_1

$$L_{in1} = 10 \log 10^{0,1L_{in1}} \leq 10 \log s_1 u_1 10^{0,1L_{eqi}}$$

or

$$u_1 \geq 10^{0,1(L_{in1}-L_{eqi})} \; / \; s_1 = 0,29 \, .$$

From the vertical axis the maximal value of $\boldsymbol{u_1}$ is calculated accordingly.

$$L_{in2} = 10\log 10^{0,1L_{in2}} \leq 10\log s_2(0,9 - u_1 J_1)10^{0,1L_{eqi}}$$

or $$u_1 \leq 0{,}9\text{-}10^{0,1(L_{in2}\text{-}L_{eqi})} / s_2 = 0{,}52$$

Both these constraints define the feasible area for u_1 or using the estimated values from fig.8 it gives

$$0{,}29 \leq u_1 \leq 0{,}52 \quad (9)$$

The same considerations are applied for Intersection N_3. The input traffic flow for the horizontal direction must be less than the output one during the green phase u_3, which results to the noise equilibrium as the inequality

$$L_{in3} = 10\log[\rho s_1 u_1 10^{0.1L_{eqi}}] \leq 10\log(s_3 u_3 10^{0.1L_{eqi}})$$

Applying the worst case, when u_1 has maximal duration, following (9) this gives

$$u_1^{max} = 0{,}9 - 10^{0.1(L_{in2}-L_{eqi})} \quad / \quad s_2$$

Using this value the upper level of u_3 is obtained accordingly

$$u_3 \geq \frac{s_1}{s_3}(0{,}9 - \frac{10^{0,1(L_{in2}-L_{eqi})}}{s_2}) = 0{,}64$$

The traffic equilibrium on the vertical axis will result on noise level, which will give the upper bound of u_3 **like**

$$L_{in4} \leq 10\log[s_4(0{,}9 - u_3)10^{0.1L_{eqi}}]$$

or $$0.64 \leq u_3 \leq 0.74 \quad (10)$$

Relations (9) and (10) determine the feasible area of control variables. The descriptions of the noise equilibrium equations will define the analytical description of the constraints of the optimization problem:

· for junction N_1, horizontal axis:

$$L_1(1) = 10\log\left[10^{0,1L_1(0)} + 10^{0,1L_{in2}} - s_1 u_1 10^{0,1L_{eqi}}\right];$$

·for junction N_1, vertical axis

$$L_2(1) = 10\log\left[10^{0,1L_2(0)} + 10^{0,1L_{in2}} - s_2(0{,}9 - u_1)10^{0,1L_{eqi}}\right];$$

·for junction N_3, horizontal axis:

$$L_3(1) = 10\log\left[10^{0,1L_3(0)} + 10^{0,1L_{in3}} - s_2 u_3 10^{0,1L_{eqi}}\right];$$

where

$$\mathrm{L_{in3}} = \rho u_1 s_1 10^{0.1 L_{in2}}$$

·for junction N_3, vertical axis:

$$L_4(1) = 10\log\left[10^{0,1L_4(0)} + 10^{0,1L_{in4}} - s_4(0,9 - u_3)10^{0,1L_{eqi}}\right]$$

The goal function of the optimization problem was given physical meaning as equivalent noise level, originated by the multiple noise sources from the intersections plus a components fo the control variables

$$J = 10\log\{(10^{0.1L_1(1)})^2 + (10^{0.1L_2(1)})^2 + (10^{0.1L_3(1)})^2 + (10^{0.1L_4(1)})^2 + (u_1 10^{0.1L_{eqi}})^2 + (u_3 10^{0.1L_{eqi}})^2 \quad (11)$$

The explicit analytical description of the optimization problem becomes

$$\underbrace{minJ}_{\substack{u_1,u_3 \\ L_1,L_2,L_3,L_4}} \quad (12)$$

$$L_1(1) = L_{eqi} + 10\log(\alpha_1 - s_1 u_1),$$
$$L_2(1) = L_{eqi} + 10\log(-\beta_1 + s_2 u_1),$$
$$L_3(1) = L_{eqi} + 10\log(\alpha_3 + \rho s_1 u_1 - s_3 u_3),$$
$$L_4(1) = L_{eqi} + 10\log(-\beta_3 + s_4 u_3),$$

Where

$$\alpha_1 = 10^{0,1(L_1(0)-L_{eqi})} + 10^{0,1(L_{in1}-L_{eqi})}$$
$$-\beta_1 = 10^{0,1(L_2(0)-L_{eqi})} + 10^{0,1(L_{in2}-L_{eqi})} - 0,9\, s_2,$$
$$\alpha_3 = 10^{0,1(L_3(0)-L_{eqi})}$$
$$-\beta_3 = 10^{0,1(L_4(0)-L_{eqi})} + 10^{0,1(L_{in4}-L_{eqi})} - 0,9\, s_4.$$

The solution of this constrained problem (12) is found by substituting $L_i(1)$, i=1, 4 in J and then the minimum of J is calculated in regard to the boundaries (9) and (10). Analytical solutions of the optimization problem (12) can be found by the system equations

$$u_1^* = \arg\{dJ/du_1 = 0\} \quad \text{and} \quad u_3^* = \arg\{dJ/du_3 = 0\}.$$

After a few algebraic operations the optimal solutions for the green light durations are

$$u_1^0 = \begin{cases} u_1^* \; if \; 0,29 \le u_1^* \le 0,52 \\ 0,29 \; if \; u_1^* \le 0,29 \\ 0,52 \; if \; u_1^* > 0,52 \end{cases} \quad u_3^0 = \begin{cases} u_3^* \; if \; 0,64 \le u_3^* \le 0,74 \\ 0,64 \; if \; u_3^* \le 0,64 \\ 0,74 \; if \; u_3^* > 0,74 \end{cases} \quad (13)$$

The analytical relations (13) allow the control algorithm to be implemented in a closed loop. The control system continuously performs data acquisition for the noise levels for the upstream traffic $\mathrm{L_{in}}$ and the resulting noises of the queue lengths in front of the traffic lights $L(0)$. The optimal green signals are calculated following (13) and they are applied on each control step k.

Simulation procedure was applied for accessing the control policy, described by relations (13). The resulting behavior of the noise equilibriums are given in Fig.9. The initial data for the simulation are taken from real measurements of the cross road section, which are part of Sofia transportation network. The estimated initial data are: $\rho=0.9$; $L_{in1}=69.33$, $L_{10}=71.23$, $s_1=1500$; ; $L_{in2}=69.21$, $L_{20}=73.11$, $s_2=1100$; ; $L_{30}=74.41$, $s_3=1100$; ; $L_{in4}=65.75$, $L_{40}=72.23$, $s_4=1200$. The optimal evaluation of the green lights was compared with the current fix stated durations on this crossroad section. The simulation results considerably improve the integral behavior for the noise equilibriums. The notation used are L_i , for the optimization case according to (13) and L_{in} for the fix time current durations of the traffic lights. It is seen that the traffic noises decreases on the crossroad sections. The total equilibrium case, accessed be the behavior of the value of the goal function gives considerable advantages for the optimization case, fig.10. Thus the optimization problem provides better policy for traffic control as reduction of the level of the noise pollution for the overall traffic region.

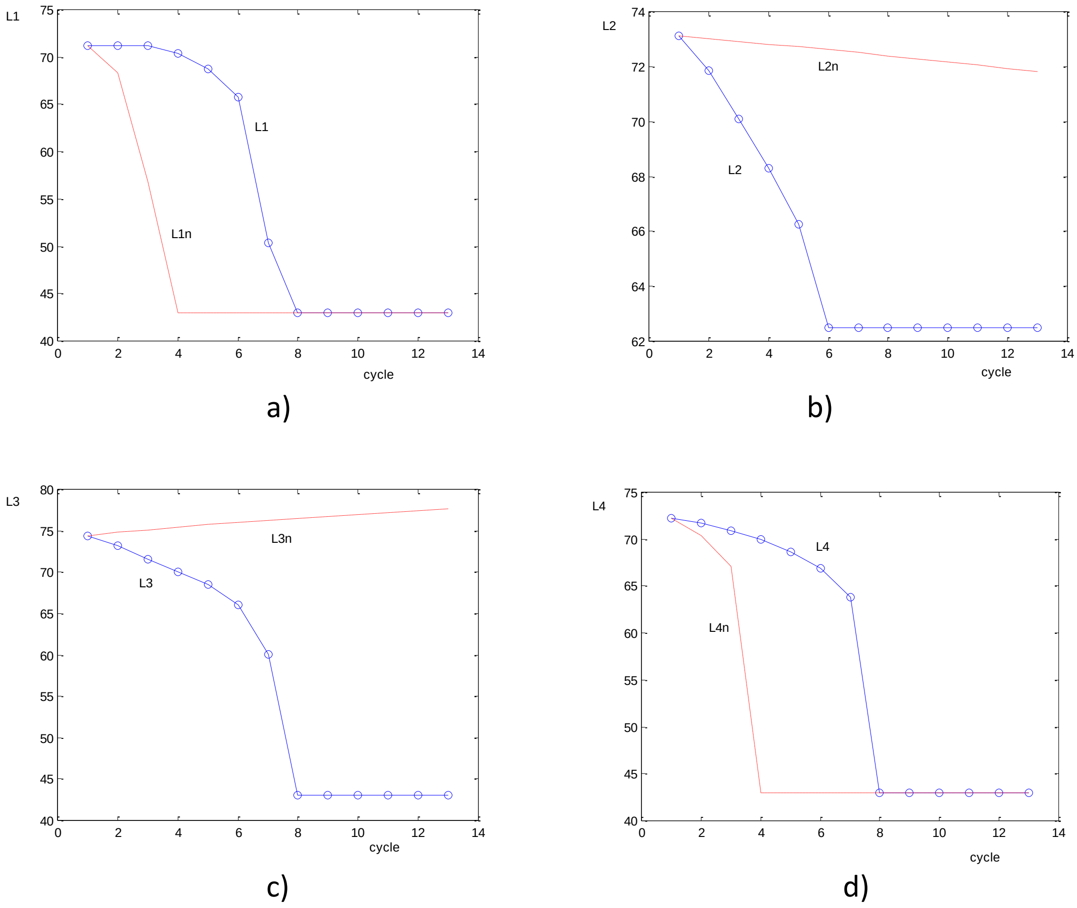


Figure 9. Comparison of Noise levels with (L_i, i=1,4) and without (L_{in}, i=1,4) control of green lights

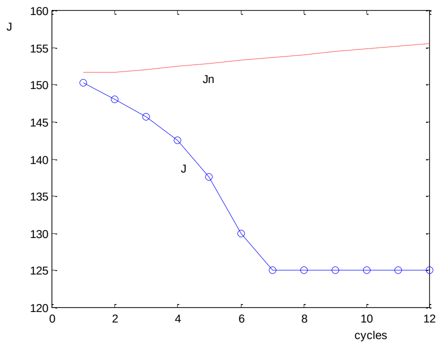


Fig.10. Traffic network: goal function with (J) and without (Jn) control

This study implements acoustic measurements for the definition of optimization problem for arterial traffic control. The optimization problem has been defined as equilibrium of the noise levels, originated from several noise sources. The noise was generated by the inflow of traffic and from the queue lengths in front of the intersections. This control policy benefits both the traffic flow optimization and the decrease of the environmental noise pollution. The simulation results, compared with the currently established fix time traffic lights durations prove the benefit of this formal model and its application in traffic lights control.

3.2.3 Actions for the ARTS Community

Traffic assignment with environmental objectives

In addition to evaluate the impact of route choice in terms of emissions, it is also important to assess the effect of information on drivers' route-choice actions. This is particularly important since its effectiveness is dependent on a reliably system that is perceived as convenient by those affected by traffic problems [34].

Although ATIS have the intention of providing more precise real-time information, it is doubtful whether drivers would ever have total confidence in these systems. Considering the complexity of developments in the field of ITS, Höltl and Stefanraises [34] have raised the interesting question: "**At what point do users start feeling overloaded and no longer able to handle all functionalities, ultimately rejecting using them**?"

Informed drivers are more prone to risk-seeking and have greater understanding of the travel time variability. By contrast, drivers with no information show to be more risk-averse and less sensitive to variability [37]. Overall, It has been demonstrated that ATIS may overcome behavioural inertia and the employ of ATIS has demonstrated to yield lower system travel time and congestion levels [36]. However, **persuade drivers to following eco-friendly route suggestions based on advanced driver assistance systems (ADAS) might be a difficult task since these systems do not provide visible direct effects**. Hence, it is important to consider the attributes that ultimately make it useful and efficient from a user's point of view [34].

Development of simulation platforms for environmental (and even social) impacts assessment of transportation policies: future trends

- Propose the use of a more extensive analysis of environmental impacts of traffic defined in the new polices and European Directives;

- Propose rules to establish the baseline scenario and the BAU scenario;
- Propose rules to define the meteorological year to assess road traffic polices;
- Analyse the variables which have a high impact on further applications when a spatial projection is required. Define tools to automatic quantify and control de error propagation across models.

Policy and barrier legislation (*Tiziana Campisi, Enna University and Nicolette Formosa, Malta University)*

Introduction

Fully autonomous vehicles (autonomic too) are a longer term goal of both policy makers and manufacturers, with EU and UK technology roadmaps predicting they will be on sale from 2025 and Google predicting 2017.

However, there are issues to address with the technology, with public perception and with the regulatory framework. These will have a major influence on how soon the technology can be adopted. This chapter shows the problem to breakdown barrier legislation related to this research field. In fact today major problems are related to:

- Technology Liabilities: Computer Bugs
- Technology Liabilities: Artificial Intelligence
- Full shutdown on bug discovery
- Computer attack
- Non-Technological Issues
- Insurance
- Liability

Many have said that the technology in robocars is ahead of the current policy.

According to *Bernard Lu, senior staff counsel for the California Department of Motor Vehicles, he says that, "If you look at the vehicle code, there are dozens of laws pertaining to the driver of a vehicle, and they all presume to have a human being operating the vehicle."*

This can create particularly tricky situations such as deciding whether the police should have the right to pull over autonomous vehicles, a question yet to be answered.

Even the chief counsel of the National Highway Traffic Safety Administration admits that the federal government does not have enough information to determine how to regulate driverless technologies. This can become a particularly thorny issue when there is the first accident between autonomous and self-driving vehicles and how to go about assigning liability.

The growth of self-driving vehicles is occurring at a rapid pace. With the increase of autonomous cars a number of potential advantages and obstacles are present, which also influences society in general. This section includes the overall societal impact due to the advancement in autonomic driving. However, this advancement is also dependent on the legislative bodies and laws which are already in act. Hence, it identifies the legislative bodies and laws related to autonomic transportation and shows that the adoption of such transportation still poses barriers for acceptance and implementation.

SOCIETAL IMPACTS

The path to achieve the main objective of partially autonomous and fully autonomous cars is very challenging as it will affect infrastructure planning and investments, legal adaptation, technology developments, changing road user's conception of traffic and driver education. Thus, such transportation will affect the main stakeholders involved: industry, governments, authorities, researchers, infrastructure developers and the general public.

INVESTMENTS IN INFRASTRUCTURE

The major cost to society is due to investment in infrastructure. In fact, the cost per km for an urban highway is expected to increase over the next years [1] [2]. The impact of autonomous vehicles can however reduce the cost of infrastructure by reducing the infrastructure that otherwise would be necessary. An example is that the directional devices built into the infrastructure are built in directly in autonomous vehicle thus resulting in a lane width reduction. More lanes can fit in if there is a reduction in lane width and thus reduce investments and increase savings. Not only so, but autonomous driving can optimise the city landscape and improve traffic flow.

PERSONAL AND SOCIETAL BENEFITS

In the continuous development of various levels of assistance systems leading up to fully autonomous systems, there are potentially a number of possibilities for societal benefits. From an individual perspective, the main benefit from autonomous driving would be to recapture the true freedom behind the wheel.

A fundamental benefit can be the relief of the vehicle occupants from driving and navigation chores. As stated previously, an autonomous driving vehicle could open up possibilities for other activities such as leisure, work and social interaction. Improved health status due to more time available for personal use is also a factor that may be added to the benefits. Wasted time in traffic can be linked to a financial loss, this both from an individual point of view and a societal point of view. Being able to use time more efficiently when commuting to and from work can add valuable time to read emails, book meetings etc. This will free-up time at work for more useful meetings and discussions where personal presence is necessary. The time in the car can also be used more efficiently for private matters, such as reserving time with a doctor, arrange cinema tickets etc. Automated driving may have an equal opportunity factor by offering mobility to users that would normally not be able to drive. Blind, physically challenged or persons without driving licenses could potentially own and ride a car with autonomous driving features and so remove constraints on the occupants’ state. This could also lead to fewer traffic collisions for drivers who would be distracted or intoxicated. A sustainable business case require benefits like time and reduced fuel consumption. The direct value of having vehicles with autonomous driving capabilities can be estimated based on time saved and reduced fuel consumption. The value for the driver is higher when adding comfort of travel and gained freedom.

Autonomous driving could also open up for benefits such as the possibility of using commuter lanes, bus-lanes, reduced city tolls, access to certain restricted areas, using specially assigned parking areas, etc. The event of a crash free society could open up for new opportunities for vehicle interiors and removing some restrictions for the occupants positioning in the interior compartment. If there is no crash risk, occupants will not need the seatbelt and may have the possibility to move around freely inside the vehicle that would even further improve riding comfort. If crashes and incidents can be avoided or reduced, the costs for insurance are likely to come down, which directly impacts the total cost of owning a motor vehicle. Autonomous driving systems will make it possible to utilise the available road space more efficiently. By coordinating traffic flow, i.e. speed and distance between vehicles, congestions can be reduced, and the traffic flow through cities increased. With improved control of distance between vehicles, the static distance can be reduced in slow moving traffic, but also reduce dynamic distance between vehicles in stop-start traffic scenarios. Traffic flow speed in congestion is often reduced by delays in stop-start traffic, but also narrow sections and access points. If the speed can be increased by automated control in these sections, an increased overall traffic flow can be reached. Reduced distances between cars and increased traffic flow speed require increased knowledge of the environment around the vehicle. There are studies in the US, that show that the efficiency for traffic with autonomous vehicles increases up to 273% [1]. Although this figure appears to be on the overestimated side it is clear that autonomously driven vehicles will help to improve traffic flow.

Cost Savings from Avoiding Accidents

Safety issues have the most serious impact on daily life out of all the transportation problems. Traffic accidents have negative effects on the economy. The different studies of annual savings for road casualties' fatality in Europe is of around 1.6 million EUR per avoided fatality, 70,000 EUR per avoided injury and efficiency benefits of avoided casualties (add on to road safety): 15,500 EUR per avoided fatality accident, 5,000 EUR per avoided injury accident [3]. In the US, in a study published in 2011, shows that the total cost for car crashes is estimated to be around 300 million USD with a cost per fatality of 6 million USD and 126,000 USD per injury [2]. From the studies being released during the last couple of years, assistance systems have proven to yield a number of clear safety enhancements and reduction of both casualties and reduction of societal costs. In one of the studies [4] the British motor vehicle research institute Thatcham has estimated the saved repair costs if all vehicles in the UK were equipped with an automatic emergency braking system similar to the Volvo City Safety system to around 1.3 billion Euros annually. The saved societal costs for avoiding injuries per year would be nearly 2 billion Euros.

Human error a major cause in more than 90% of accidents and almost 75% of the cases human error is the only cause. A study shows that applying the brakes half a second earlier in a car traveling at 50 km/h can reduce the crash energy by 50%. Using the German accidents for analysis, 39% of drivers didn't activate their brakes before the collision, and 40% didn't apply brakes effectively [5]. Human beings are far from being perfect drivers and consequently the use of autonomous vehicles can greatly reduce the number of crashes.
According to EUROSTAT data, the number of road fatalities in the EU has been reduced over the years. This reduction goes to show that the advancements in safety precautions of recent vehicles reduce accidents when compared to previous vehicle generations. Moreover, the financial burden of each accident to the community is very high as well as the social effect on people. In a fatal traffic accident the person's intelligence, workforce and social values are lost. Additionally in the case of injuries, the financial effects are also large as the treatment costs are very high, and the injured people are unable to work for a period or can remain permanently impaired.

IMPACTS ON DRIVING

The traffic flow with autonomous vehicles would drastically change. The average person in the United States waits over 26 hours in traffic during the whole year. This is a very large amount of total wasted time spent waiting. At the initial period of implementation of autonomic cars, there would be a combination of autonomously driven vehicles and human-controlled vehicles. Problems might arise concerning the reaction of motorists to the driverless vehicles and on the integration of the autonomous into the traffic flow. While the autonomous vehicles would be following all traffic laws, the human drivers have the option not to.

With further developments, the autonomous car will become a more commonly used vehicle on the road and so traffic would become less congested, and cars would be able to merge into moving traffic and exit easily. Moreover, with the reduction of traffic, vehicles could be designed to optimise fuel usage at common speeds used on the road. The car would be able to adjust its speed according to the communication between vehicles or GPS traffic data. This would enable the car to optimise its driving (less stop and go) while reducing travel time and consumption.

Car-pooling would further increase so less private cars will be on the road. The vehicle would be able to pick a person up and also drop them off, allowing the car to drive multiple people to different destinations. Having fewer vehicles and many or all of them on the road at a consistent speed would result in far fewer traffic jams. This results into people being happier with their drive and it also reduces the amount of time a person must wait on the road. Hence resulting in improving the overall efficiency of society. This would eventually force the average person to be more on time without the need for over-speeding to make it in on time.

One of the major problems related to traffic and congestion is parking. In an autonomous transportation system, cars would be able to go and park themselves at a more distant location and come back when requested. This is more convenient as it will help reduce congestion in the road as well as save time looking for a parking space.

FUEL ECONOMY

The best fuel efficiency is when the vehicle is operating at optimum performance (eliminating ineffective speeding up and braking). If the fuel efficiency is improved by only 1%, it would still result in billions of euro saved throughout the year. Additionally, the fuel expenditures are getting higher every year as the number of vehicles increase, and fuel prices are also increasing, which points out the importance of saving fuel. An aggressive driver uses up to 33% more fuel than the average driver and an average driver uses about 10% more fuel than most efficient driving possible [3]. Consequently, it would be reasonable to say that autonomous vehicles will be saving more than 10% fuel on average. As discussed previously, if the risks of having an accident decreases and all the cars in use become automated; this will enable all the vehicles to be lighter with the absence of safety features. Lighter cars will save up to 2% fuel for every 100 pounds of weight dropped [3]. Improved traffic flow would also result in fuel savings, the reason being that most fuel is consumed in stop and go traffic scenarios. In current driving conditions, most drivers usually stop very often, drive too slow because of bad traffic conditions or drive too fast on the highway to reach their destination. With the implementation of a fully autonomous system, vehicles can travel more efficiently in urban areas as well as highways. This will cause the in city mileage limit of vehicles to get closer to increases to that of the highway limit. Although, improving the level of the efficiency in urban areas to the highway levels will not be possible; the efficient flow of traffic in cities can easily save about 10% on fuel costs.

PROFESSIONAL DRIVING

Shipping

One way to transport goods on land is by freight trucks, and autonomous vehicles will have a huge impact on the land shipping industry. There are thousands of freight trucks everyday on the road with a driver driving for more than one day to reach their destination paid by the trucking company. If the trucks were able to drive on their own, a person to move the vehicle from one point to another is no longer needed. An additional advantage is that the truck does not have needs such as hunger, tiredness other than the need to re-fuel. This would lead the company to make huge savings with the downside that people will lose their job.

Delivery services such as FedEX or UPS could have vehicles driving house to house dropping off packages to people using autonomous cars. Again, this saves a huge amount of money for the industry but results in a reduction of jobs. This can however be compared to the industrial revolution and what it did to the workforce in the early 19th century. Automation in reality did not eliminate jobs but displaced workers in entirely new fields.

Taxi Services

Another business that would be strongly affected is taxi services. It is based solely on driving someone around who does not have a car or does not want to drive. Then the employee is dispatched to go and pick up a person and bring them to their destination. This type of service could lower the number of vehicles on the road because not everyone would have to own a car, people could call to request an autonomous car to get them around. Taxis also drive around cities and wait in busy areas for people to request a cab. A taxi service comprised completely of autonomous vehicles could be started. A person can call in and request to be picked up and then be brought to their destination for a fee. There could be autonomous taxis waiting in designated areas for people to come and use them. Many taxi drivers need the job because they are unable to perform other jobs for various reasons. The need for a human in the service goes away almost completely. This is another example of a large amount of people being removed from their jobs because of autonomous vehicles being able to perform the task without the need of an extra person.

An autonomous vehicle can replace two taxi drivers in the eyes of the employer as the vehicle requires no resting and can be on the road as long as it has fuel (and even then it will know when it needs to fuel up so it can return the road as quickly as possible). A taxi business can invest the money in autonomous systems and result in profits rather than having taxi driver salaries if an autonomous vehicle system can last for eight years.

People could also own part of a car like they would a timeshare or a shared private jet. Different people buy a share of the vehicle and then can request specific times to use it, or it can be set up on a schedule of when people can use it.

Public Transportation

Public transportation is typically controlled by a human operator, such as on a bus, in a train or subway. Typically there is a person sitting in the driver’s seat, and they are controlling what the vehicle is doing. The driver’s job also includes many tasks that one person must be able to handle and control at the same time. In the early stages of implementation, the driver will still be behind the wheel as a safeguard as well as for the general public to trust it at first. As the development on autonomous cars progresses, drivers would no longer be needed as the system would be able to perform all of the required tasks. The public transport would need to follow a specific route and to stop at designated points. The problems would arise from actions of other vehicles in the area. An ideal situation to adopt such a system for public transport is when nearly every vehicle on the road is autonomously driven. This would allow for information exchange between vehicles so they can know the planned moves and choices that another vehicle in the environment will make. In the end, drivers will no longer be needed to run the bus transit system, and this would bring about a large savings to public transport companies while resulting in drivers losing their job.

Nearly all forms of professional driving could be taken over by autonomous systems that can perform the task without being paid or given benefits. This brings a huge money saving for companies that run transportation systems, but it will put thousands of people out of work. There would need to be much discussion on how to handle this issue before autonomous systems are brought to realization.

CULTURAL CHANGES

There are many cultural traditions that revolve around being able to drive a vehicle, and it is considered as a major milestone in a young person's life is getting a drivers' license. Correspondingly, useful knowledge of the roads comes with getting a drivers' license. However, if the vehicle knows how to drive and follows all of the rules it would not be essential to learn all of the information and that learning curve would be lost. If autonomous vehicles became widespread, it would no longer be a necessity to get a drivers' license. A vehicle can pick a person up from any location and drop off to any destination. It will no longer be desirable to own a personal vehicle when one can be easily shared among multiple people. A family owned autonomous vehicle would be able to service the entire family. There is no longer a need to have the parents drive the children to drop them off at the destination because the child is too young to drive on their own. This would be a revolutionizing impact on family life. However, these types of changes would only occur when the autonomous vehicle is widespread.

BETTER MAINTENANCE

An automated vehicle could take itself to gas stations or regular service and repair, provided that those services are arranged for autonomous vehicles. These self-maintenance abilities can save time and make sure that the car is in good shape at all times. The automated vehicles will also minimize the abuse of the vehicle in a way so that the minimum service or spare parts will be required. As a result, cars will experience fewer breakdowns and have a longer engine life while being more cost-effective and reliable. A very important effect of the self-maintenance ability would be minimising the number of crashes that are caused by technical faults.

POLICY AND LEGISLATION

There is no explicit legislation which governs autonomous vehicles on UK roads. UK traffic regulations are based on the Vienna Convention on Road Traffic (1968) which requires the driver be in control of his or her vehicle at all times. The UK has signed but not ratified this convention. When testing prototypes of autonomous vehicles, a human is always present in the driving seat in order to take over in case of fault, so the systems remain in compliance. If the driver is engaged with other tasks, then handover of control is not instantaneous and this would not comply with the convention. This raises questions as to how autonomous vehicles could be best regulated to operate safely given the current absence of international standards.

Nowadays (2014) there is no published strategy for the adoption of autonomous vehicles in the UK. The Technology Strategy Board feels that this lack of guidance is hampering technological progress. DfT is commissioning a scoping study to look at the barriers to implementation.

LEGAL IMPLICATIONS

The existing legal framework for regulating the requirements on the driver, on motor vehicles and the infrastructure offers many challenges to achieve autonomous driving. When this framework and base work for the regulations were shaped, autonomous driving was unheard of. Given the rapid advancement in technology the legal framework needs to be revised so as not to restrict the objectives envisioned by autonomous driving. The European lawmakers struggle with the definitions and concepts of the level of autonomy that are to be allowed in the future. The Legislative bodies are:

1. The European Union (EU)
2. UNECE

The EU has legislative power and is the stakeholder responsible for establishing Community provisions in ordinances and directives in this field as well, with the exception of many of the aspects relating to road traffic rules and infrastructure design in a more physical sense. When it comes to preparing technical requirements for vehicles, this work has been delegated to the international United Nation Economic Commission for Europe (UNECE), based in Geneva. When provisions in the form of regulations have been devised, these will be sent back to the EU for regular decision-making. Alongside its role as a legislator, the EU is also initiating and financing extensive research in which the field of autonomous driving is deemed to be on the increase [paperpilot_eng]. UNECE has a range of Working Parties (WPs) in the field of road transport, but in this context WP 1 and WP 29 are of relevance.

The legal framework with implications for autonomous driving can be divided into four major parts:

1. The Vienna Convention
2. The Geneva Convention
3. State Laws
4. National Rules and Regulations.

Analysis of the laws and regulations that can impose a threat to autonomous driving is present in the following sections. In some countries, it is considered that everything is prohibited unless permitted by law. In most countries, however, everything is legal unless prohibited. This becomes an important fact when analysing the state laws and the national rules and regulations.

THE VIENNA CONVENTION

The Vienna Convention on Road Traffic held in 1968 was adopted by United Nations. This convention focuses on preventing crashes by focusing on rules for general behaviour by adopting international uniform traffic rules. Such rules specify the requirements on, among other things, sign and signals, traffic education, speed and distance between vehicles, instruction by officials and the driver's physical and mental condition and ability, skill and alertness.

In Article 8, Drivers, it is specified that:

1. Every moving vehicle or combination of vehicles shall have a driver.
2. It is recommended that domestic legislation should provide that pack, draught or saddle animals, and, except in such special areas as may be marked at the entry, cattle, singly or in herds, or flocks, shall have a driver.
3. Every driver shall possess the necessary physical and mental ability and be in a fit physical and mental condition to drive.
4. Every driver of a power-driven vehicle shall possess the knowledge and skill necessary for driving the vehicle; however, this requirement shall not be a bar to driving practice by learner/ drivers in conformity with domestic legislation.
5. Every driver shall at all times be able to control his vehicle or to guide his animals.

The Vienna Convention does not have the authority to specify requirements on vehicle performance, but only concerns the state of the driver. It does not restrict how the control of the car can be handed over to the vehicle systems. However, there is a specific restriction to the possibility to hand over the control of the vehicle from the driver to the in-vehicle systems. Thus, the Vienna Convention must be amended to cater for the already introduced driver assistance systems that do temporarily assume the control from the driver. This interpretation in practice also illegalises Partial and Fully Autonomous Systems until an amendment has been made to this article. Some governments, such as the Swedish and Belgian governments are supporting that the convention only makes specifications for the state of the driver, whereas the German government supports that the driver must always be in control and that Highly Automated or Fully Automated system are violating this paragraph in the Vienna Convention.

THE GENEVA CONVENTION

The Convention on Road Traffic signed at Geneva in 1949 was established to have uniform rules for international traffic in a foreign country.

Article 8 reads:

1. Every vehicle or combination of vehicles proceeding as a unit shall have a driver.
2. Draught, pack or saddle animals shall have a driver, and cattle shall be accompanied, except in special areas that shall be marked at the points of entry.
3. Convoys of vehicles and animals shall have the number of drivers prescribed by domestic regulations.
4. Convoys shall, if necessary, be divided into sections of moderate length, and be sufficiently spaced out for the convenience of traffic. This provision does not apply to regions where migration of nomads occurs.

5. Drivers shall at all times be able to control their vehicles or guide their animals. When approaching other road users, they shall take such precautions as may be required for the safety of the latter.

The commonly accepted interpretation of this based on the history behind the Geneva Convention is that it is about unsupervised animals but not unsupervised cars. Thus, the Geneva Convention does not restrict the use of automated vehicles.

State laws

In some states, everything is allowed unless it is specified to be prohibited by law. No specific state laws restrict the licensing of autonomous vehicles and so no principle barriers exist which would prevent automakers from receiving a license for autonomic cars. However, in the US in order to facilitate testing on public roads, state law- and rule makers have been preparing and adopting laws and regulations specifying rules for licensing automated vehicles. Among the states that have passed laws, as of February 2013, are Nevada, California and Florida.

National Rules and Regulations

Many countries around the world have regulations to regulate the behaviour of the driver in relation to road traffic characteristics. Such regulations include for the driver to be cautious and to have a practical behaviour. A typical example includes the minimum distance between cars while driving which is an important safety measure if a human is driving. However, if the case of an autonomic car which is continuously communicating with other cars in the environment, the braking distance can be made shorter.

Safety Certification

Automated systems are becoming a safety requirement in consumer rating programmes for new cars: Automated emergency braking in response to other vehicles will be necessary from 2015. Without this, the highest (5*) safety rating will not be obtainable. As autonomous vehicles develop, systems will be increasingly interlinked, controlling brakes, accelerator and steering. Regulatory systems currently designed to test each system separately may need to be revised. New standards capable of verifying the reliability of autonomous control software will also need to be devised.

Liability and Insurance

There is ongoing discussion about liability in the event of an accident involving a vehicle which was being driven autonomously. With the current prototype systems, liability will probably be decided on a case by case basis in the courts, but this would not be suitable for wide scale deployment. The insurance industry would also need to update their processes as current risk modelling is based on the behaviour of a human driver. The SMMT suggests that increasing levels of automation will need to be supported by developments within the insurance and legal sectors. Cyrus Pinto [1] examines the technological and non-technological liabilities of autonomous vehicles, as well as policy aspects of robocars, using the Google self-driving car as an example. Self-driving cars have the potential to reduce the number of accidents and associated deaths and economic losses, but only if they are highly reliable.

The possibility of software bugs, other technical problems, and associated liability and insurance issues raise barriers to the use of these vehicles. The State of Nevada has adopted one policy approach to dealing with these technical and policy issues. At the urging of Google, a new Nevada law directs the Nevada Department of Motor Vehicles (NDMV) to issue regulations for the testing and possible licensing of autonomous vehicles and for licensing the owners/drivers of these vehicles.

There is also a similar law being proposed in California with details not covered by Nevada AB 511.He evaluates the strengths and weaknesses of the Nevada and California approaches, in light of the technical and legal challenges currently facing these new autonomous vehicles.

Ultimately Nevada AB 511 and California SB 1298 do not effectively reduce either the technological or non-technological liabilities, but rather set the foundation for future policy for which I make recommendations.

A vehicle driven by a computer on public roads opens the possibility of many insurance and liability issues. Even with near-perfect automated driving, there may be instances in which a crash is unavoidable. AVs have sensors, visual interpretation software, and algorithms that enable them to potentially make informed decisions. Such decisions may be questioned in court, even if the AV is technically not "at fault". If AVs are held to a much higher standard that human drivers, AV costs will rise and fewer people will be able to purchase them. Some steps have been made to account for liability concerns. California law (CIS 2013) requires 30 seconds of sensor data storage prior to a collision to help establish fault, assuming that the AV has been programmed and tested properly. Related technologies like parking assist and adaptive cruise control may provide test cases to guide how fully autonomous technologies will be held liable.

Roger Noll mentioned that he would be very interested to see if the Google autonomous vehicle is currently insured. Current California automobile insurance legislation would not be favourable for autonomous vehicles. California's Proposition 103 dictates that any insurance policy's price must be based on weighted factors, and the top 3 weighted factors must be:

- driving record,
- number of miles driven
- number of years of experience.

Other factors like the type of car someone has (i.e. autonomous vehicle) will be weighed lower. Subsequently, this law makes it very hard to get cheap insurance for a robocar. This question of insurance depends on the probability of an accident, which for autonomous vehicles would be much lower than the average driver.

US Experiences: Nevada Policy: AB 511 Outline and California Policy: SB 1298

The parts of AB 511 we will focus on Section 8, which requires the DMV to adopt regulations authorizing the operation of autonomous vehicles on highways within Nevada. In particular section 8 defines an "autonomous vehicle" to mean a motor vehicle that uses artificial intelligence, sensors and global positioning system coordinates to drive itself without the active intervention of a human operator.

This short piece of legislation accomplishes the goal of setting good standards for the DMV to follow.

By setting general standards (part a), insurance requirements (part b), and safety standards (part c), this sets a precedent for these areas without being too limited with details, leaving them to be decided by the DMV instead of the politicians.

The legislation goes on to establish guidelines for the testing (parts d and e) which are extensive and we will cover in the regulation portion the paper, and finally, the legislation leaves open the possibility of future standards to be instituted (part f).

Although these pieces of the policy set the foundation for testing cars in Nevada and future regulation, they do not provide enough details to sufficiently address the liabilities posed by technical and non-technical issues. For instance, part b only discusses insurance briefly, saying the state must, “Set forth requirements for the insurance that is required to test or operate an autonomous vehicle on a highway within this State.” In the context of this legislation, autonomous driving is seen as a binary system of existence, but in reality, it falls more under a spectrum.

However, testing and certifying this technology on par with the Google Car would be cumbersome. Despite the harmless intent behind the legislation, it can be misconstrued in controversy over legal interpretations. Legal hurdles arise in both current and old legislation alike.

In California, there is an antiquated law that says women cannot drive a car in a housecoat. This law only applies to a certain part of California, and is an example where policymakers could look closely at the laws of forty-nine other states and countless municipalities to ensure our laws behind the autonomous vehicles are in compliance.

Another California law supposedly holds that “No vehicle without a driver may exceed 60 miles an hour.” One could interpret this law as saying that robocars may travel up to 60 MPH in California, which could be a positive aspect while initially testing out the vehicles in urban street traffic, but create complications when testing autonomous vehicles on the freeway.

This special legislation and testing process raises the question about whether Google will consider testing their vehicle in Nevada since they have already done so in California. The answer seems to be yes, as Jay Nancarrow, PR manager at Google, said Google will probably apply to test in Nevada to examine how the vehicle behaves in different terrain and weather. The cars have had little exposure to snow, and this experience will be crucial in order to scale the technology.

Overall, AB 511 did not address either the technological liabilities and barely mentioned the non-technological liabilities that are necessary to overcome for future success of autonomous vehicles. Since it was the first type of legislation to ever approach the issue of autonomous vehicles, it is understandable that the policymakers did not want to go into specifics and instead rely on future regulation to determine the details

While California, Florida, Michigan, Nevada and the District of Columbia all have approved autonomous vehicle legislation and another 14 states have considered related measures,9 some question whether this legislative activity is really necessary, at least in this early stage in the development of the industry. According to a 2012 white paper from the Centre for Internet and Society at Stanford University Law School “(existing) state vehicle codes probably do not prohibit— but may complicate—automated driving.”

The author of the *white paper* expanded on that statement in a February 2014 telephone interview. “In the short term, any kind of testing that you’re going to see of cars that look

like cars will be with safety drivers sitting at the wheel ready to take over, who regularly do take over and that are really no different than driving a normal car or driving a research vehicle, which happens already fairly frequently," said Stanford Law's *Bryant Walker Smith.[2]* "It's another means of driver assistance. That's not to say it's without issues or potential concerns, but in terms of how the motor vehicle code applies, there are really no big obstacles."
Smith said it's not clear that states like Michigan or California [3], which have a large industry presence and active testing taking place, need legislation, let alone states without those characteristics. "It's also not clear that the legislation that has been passed does anything to address the more substantive questions that will arise as vehicles start reaching the public," he said. "The best thing I think that a state can do if it has any sort of active automotive presence—that is, suppliers, (original equipment manufacturers),

A guide for policymakers issued by the Rand Corporation in January 2014 found that such legislation "may create a patchwork of conflicting regulatory requirements.
It is also unclear whether such measures are necessary, given the absence of commercially available vehicles with this technology and the absence of reported problems to date with the use of this technology on public roads."

Bryant Walker Smith purpose [4] to assess the current legal status of automated vehicles. However, the article includes draft language for U.S. states that wish to clarify this status. It also recommends five near-term measures that may help increase legal certainty without producing premature regulation. First, regulators and standards organizations should develop common vocabularies and definitions that are useful in the legal, technical, and public realms.
Second, the United States should closely monitor efforts to amend or interpret the 1969 Vienna Convention, which contains language similar to the Geneva Convention but does not bind the United States. Third, NHTSA should indicate the likely scope and schedule of potential regulatory action. Fourth, U.S. states should analyse how their vehicle codes would or should apply to automated vehicles, including those that have an identifiable human operator and those that do not.
Finally, additional research on laws applicable to trucks, buses, taxis, low-speed vehicles, and other specialty vehicles may be useful. This is in addition to ongoing research into the other legal aspects of vehicle automation. Current law probably does not prohibit automated vehicles—but may nonetheless discourage their introduction or complicate their operation.
Key issues include the precise definition of these human-machine systems, the concept of control under the Geneva Convention, the potential for future regulation by the National Highway Traffic Safety Administration, and the application of myriad state laws concerning drivers and driving behaviour. Five near-term recommendations might provide some initial clarity without placing law too far ahead of technology.
First, regulators and standards organizations should work to develop common vocabularies and definitions that are meaningful in both law and engineering and accessible to the public and the media. Second, the United States should closely monitor efforts to amend or interpret the Vienna Convention as an example for or caution regarding any potential effort to clarify the Geneva Convention. Third, NHTSA should provide public guidance about the likely scope and schedule of any initial regulatory action it may take with respect to

automated vehicles. Fourth, states should closely examine their vehicle codes to determine how those codes would or should apply to automated vehicles both with and without an identifiable human operator.
Finally, there may be value in further research on the regulatory regimes applicable to special motor vehicles, including taxicabs, trucks, buses, personal transporters (including Segways), golf carts, and low-speed vehicles.
These technologies are important as potential applications for automated vehicles, and these regimes are important as potential analogies for the specific regulation of such vehicles. More generally, the law plays a crucial role in creating, defining, discussing, and managing many of the risks and opportunities posed by automated vehicles. Clearly understanding the current legal status of these vehicles is therefore an important step toward ultimately realizing their potential.
Autonomic vehicles present many opportunities, benefits and challenges while ushering in new behavioural changes. The speed and nature of the transition to a largely AV system are far from guaranteed; they will depend heavily on purchase costs, as well as licensing and liability requirements.
Moreover, AVs present security and privacy risks. Even with a smooth and rapid deployment that addresses security and privacy concerns, a system that optimally exploits AV capabilities requires special research efforts. The following outlines these barriers.

Vehicle Costs

One barrier to large-scale market adoption is AV cost. Technology needs include sensors, communication and guidance technology, and software for each automobile. KPMG and CAR (2012) note that the Light Detection and Ranging (LIDAR) systems atop Google's AVs cost $70,000, with further costs from other sensors, software, engineering, and added power and computing requirements.
Dellenback (2013) estimates that most current civilian and military AV applications cost over $100,000.
This is simply unaffordable for most Americans, with 2012 sticker prices for the top 27 selling vehicles in America ranging from $16,000 to $27,000 (Boesler 2012). As with electric vehicles, technological advances and large-scale production promise greater affordability over time. Dellenback (2013) estimates that added costs may fall to between $25 and $50,000 with mass production, and likely will not fall to $10,000 for at least 10 years.
Typical annual ownership and operating costs ranged from $6,000 to $13,000, depending on vehicle model and mileage (AAA 2012).
If AV prices come close to conventional vehicle prices, research suggests a ready market for AVs. J.D. Power and Associates' (2012) recent survey suggests that 37% of persons would "definitely" or "probably" purchase a vehicle equipped with autonomous driving capabilities in their next vehicle, though the share dropped to 20% after being asked to assume an additional $3000 purchase price. Volvo senior engineer Erik Coelingh estimates the same $3000 mark for AV capabilities (ETQ 2012), though early adopters will likely pay much more, as noted above. For comparison, as of February 2013, adding all available driver-assist features, adaptive cruise control, safety options (including night vision with pedestrian detection) and the full "technology package" increases a BMW 528i sedan's purchase price by $12,450, from a base MSRP of $47,800 (BMWUSA 2013). Of course, while these features provide guidance and a degree of automation for certain functions, full control remains with the human driver. As AVs migrate from custom retrofits to mass-produced designs, it is

possible that these cost could fall somewhere close to Coelingh and J.D. and Associates' $3,000 mark, or, eventually perhaps just $1,000 to $1,500 more per vehicle (KPMG and CAR 2012). Nevertheless, cost remains a key implementation challenge, due to the current unaffordability of even some of the more basic technologies.

Policy recommendations

Given the apparent promise of AVs, policymakers and the public would be wise to seek a smooth and intelligently planned introduction for and transition to this new technology. AV technology seems likely to advance with or without legislative or agency actions. However, the manner in which AV technologies progress and will eventually be implemented depend on these efforts. Intelligent planning, meaningful vision, regulatory action, and reform are required to address the issues identified above. As such, this report recommends three concrete actions:

Cyber Security and Privacy

In order for an autonomic vehicle to function safely, multiple backups would be needed if the communication system jams or is not available. Furthermore, autonomic cars depend on data generated by other vehicles. This, therefore, results in privacy concerns over who can have access to this data and how it might be used. Also, the communication system needs to be robust and protected from cyber-attacks. This presents a number of ethical questions.

Expand Autonomous/Autonomic Vehicle Research and their impacts

Car manufacturers have poured resources into AV technology research and development. Meanwhile research into the impacts that these vehicles could deliver to the transportation 15 system is relatively scarce. This paper has identified key missing links in AV research, including:

- Future AV market penetration rates;
- Travel and land use pattern evolution in the face of AV car-sharing and ride sharing options;
- Emissions and energy impacts of AV operations; and
- Integrated AV and ITS infrastructure investigations, including facilitation of mileage based user fees.

Other gaps will become apparent in coming year and as AVs enter the marketplace. It becomes imperative that agencies around the world and at the federal, state and local level, as well as other stakeholders help fund such research to enable regions and nations to anticipate, and more effectively plan for AV opportunities and impacts.

Develop International Guidelines for Autonomous Vehicle Licensing

To facilitate regulatory consistency, a framework and set of international guidelines for AV licensing should be discussed. With a minimum and more uniform set of standards in place, countries may devote efforts developing safety, operational, and other requirements. Existing US states licensing can provide guidance for such efforts, which will streamline AV licensing and testing. Moreover, AV licensing consistencies could help limit AV product liability, as argued by Kalra et al. (2009).[6]

DETERMINE APPROPRIATE STANDARDS FOR LIABILITY, SECURITY, AND DATA PRIVACY

Liability, security, and privacy concerns represent substantial barriers to widespread AV technology implementation. These issues should be addressed to give manufactures and investors more certainty in development. Liability standards should strike the balance between assigning responsibility to manufacturers without putting undue pressure on their product. Robust cyber security standards will help the industry develop ways to prevent outside attacks. AV technology consumers will likely have concerns about use and potential abuse of data collected from their personal travel. Therefore, AV-enabling legislation should balance legitimate privacy concerns against potential data use benefits. Since vehicles will inevitably cross state boundaries, federal regulation should establish parameters for what types of AV data to share, with whom it should be shared, how the data will be made available, and for what ends it may be used rather than take a default (no action) position, which will likely result in few to no privacy protections.

CONCLUSIONS

Driverless cars and autonomic vehicle may seem a distant possibility.
In reality, autonomous technology is improving quickly, as some automated features are already on current models. This new technology should reduce crashes, ease congestion, improve fuel economy, reduce parking needs, bring mobility to those unable to drive, and eventually revolutionize travel. Based on current research, annual U.S. economic benefits could be around $25 billion with only 10% market penetration.
When including broader benefits and high penetration rates, AVs may save the U.S. economy roughly $430 billion annually.
While this does not include some associated costs and externalities, the potential for dramatic change to the nature of transportation is very possible. While potential benefits are substantial, significant implementation and mass-market penetration barriers remain. Initial AV technology costs will likely be unaffordable for most households. States are currently pursuing their own licensing and testing requirements, which may bring a patchwork of regulations and requirements without federal guidance.
An AV liability framework is largely absent, creating uncertainty in the event of a crash. Security concerns should be examined from a regulatory standpoint to protect the traveling public, and privacy issues must be balanced against data uses.
Car manufacturers have shown interest in AVs by investing millions of dollars to make self-driving cars.
The governments should begin focusing research into how AVs could impact transportation and land use patterns, and how to best alter our transportation system to maximize their benefits while anticipating and mitigating negative impacts.
Automated driving presents a number of possible benefits to society and to the individual level. Such benefits mainly include safety and fuel economy, reduction in pollutant emissions, better mobility because of improved traffic flow and reduction in traffic congestion. Nevertheless there are still many challenges at present that needs to be addressed. Additional research is required for a better technological development,

adaptation to the infrastructure and to the interaction with other road users. Legal matters are also a critical issue which need to be addressed.

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Theme 3.3: Business Case, Environmental Benefits

(main contributor Jacek Malasek)

3.3.1 Introduction:

This section deals with the development of an objective argument for who will benefit from ARTS, and in what measure, and the specific benefits to the achievement of minimising adverse environmental impact. Achieving the goals set out by environmental policies within the context of a road network is a highly complex task. This strand will consider the opportunities and challenges in deploying autonomic behaviours, perhaps in conjunction with demand management or gating techniques, in order to provide a solution to solving environment goals, and in particular to minimise environmental impact.

The biggest challenge of sustainable transport policy in urban areas is to decrease car use in densely populated areas where the highest traffic flows are observed. Implementation of sustainable development for a smart city is to support economic growth with minimal harm for environment and high living standards. In case of sustainable transport it means less energy and land consuming investments. As mobility is one of important living standards and big achievement of our civilization, we have to be sure that any restrictions for car use will not decrease an indispensable mobility.

Environmental benefits can be directly related to transport network optimisation that will result in less fuel consumed and smoother behaviour of drivers, generating lower pollutant emissions and noise levels.

Other Environmental benefits can be achieved when Traffic Managers have to deal with complex situations, such as multiple incidents or combination of unexpected events of different nature that are difficult to manage from humans, then the implementation of an Autonomic system, that can deal and minimise the congestion, queues and travel times across the network for such complex traffic condition will result in an overall environmental impact reduction s of journey times of millions of travellers can be justified. (Fabio)

The Business Case will consider:

- User needs
- Societal impacts
- Economic benefits
- Environmental benefits
- Financial implications,

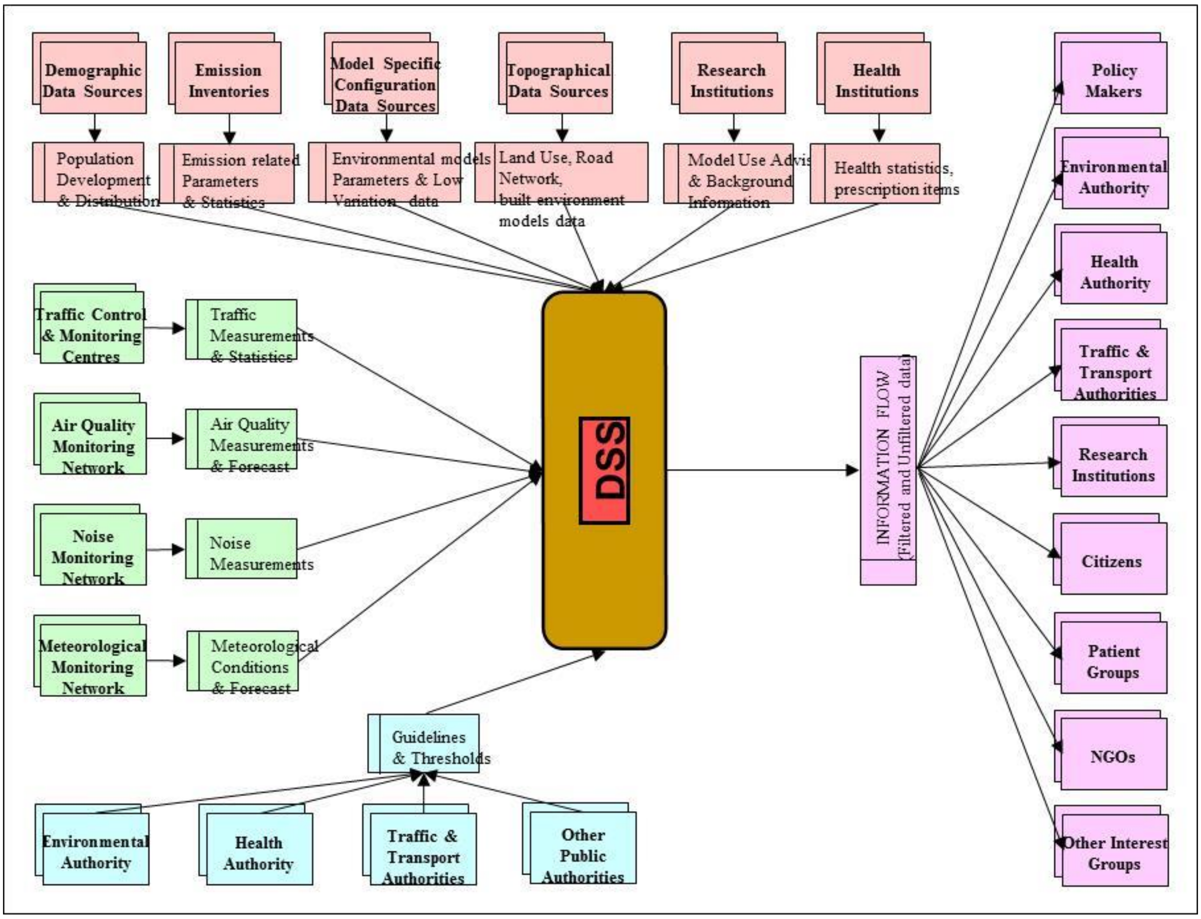
for the following end users:

- Policy Makers
- Public Authorities (Traffic, Environment, Health);
- Traffic and Transport Operators
- Citizens
- Patient Groups
- NGOS
- Travelling public,

including the following stakeholders:

- Environmental management
- Regional Control Centre (Local/Road Transport)
- e-ticketing suppliers
- Public Transport Operators
- Personal Mobility Devices
- Safety Management
- Telecommunications.

We can follow the HEAVEN's system architecture which fits our needs exactly:



3.3.2 Business Model idea and benefits

In each city several stakeholders should be involved in Smart Travel Planner (STP) implementation for fulfilling the following tasks:

- **Individuals**: To inform PIP on travel needs and try to follow social behavior principles
- **Big companies** (workplace providers): to promote tele-working, decrease capacity of parking lots, participate in PT season tickets cost, provide cycling infrastructure (a shower, etc.)
- **PT Authority**: to improve quality of operations, adjust capacity to demand and inform Traffic Management Center on-line on PT vehicles location

- ❖ **Traffic Control Center**: Avoiding traffic jams (alternative routes), informing on-line on traffic constraints, parking capacity and sectoral traffic speed
- ❖ **Environmental Dpt.**: to inform on-line on air pollution in particular areas
- ❖ **STP operator within Traffic Management Ce**nter: to gather and proceed data, advice individuals, coordinate PT and road traffic
- ❖ **Media**: to promote idea of sustainable transport using celebrities and individuals with their success stories
- ❖ **City Hall**: to implement sustainable transport policy measures (including MILU) and calculate gains of changing drivers behavior.

The Business Model idea looks like that. Financial Div. of the City Transport Dpt. calculates gains of the lower car use:

- Lower costs of road construction and maintenance
- New work places
- Shorter travel times
- Better environment
- Better inhabitants health
- Green City image

minus costs of STP implementation. We believe there will be some profit!

The profit should be used for:

- Further improving of environmental friendly travel modes (PT, P+R, cycling, etc.)
- Tax relief for participating companies
- Incentives for individual**s** (everyone gathers points for each eco-friendly choice): free PT season tickets, access to the „rare goods": best kindergarten, star concert free ticket, etc.

Rules of competition for individuals (STP users) are a part of the city Business Model:

- **Each travel mode decision is calculated** in PIP (Personalized Internet Portal) – comparing with using average (for the city) car emissions during pick-hour.
- **Social cost** (covers: emission, noise, other travelers time losses, risk of traffic accidents) **of each travel is measured** in Euro and changed on points.
- **Using a car with higher emissions one receives minus points**, when travel by e-car, a new car, on alternative fuels, etc. is awarded with plus points. **Higher number of plus points you'll receive choosing PT modes, cycling or walking**.
- **Those with the highest points number are periodically awarded** and presented by media.

This STP system (as presented above for the year 2030) will cost more than quite popular today travel planners, but its efficiency in changing, drivers behaviour, decreasing pollution, and improving traffic conditions will be higher.
Each city have to decide what quality of TMC, PIP and STP to choose – according to its budget surplus and expected gains. Cost/Benefit analysis should be here applied.

3.3.3 Actions for the ARTS Community

Success of our Business Case Model (BCM) is important for all ARTS community. Its successful pilot implementation will result in the wide support for further financing and development of another ARTS functions. Before starting BCM implementation acceptability of its general idea should be checked using a questionnaire prepared for:

- **the City** (City Hall departments for roads, environment, finances…., and for Public Transport Authority), and
- **for Smart Travel Planner (STP) users**

The questionnaire for the cities should cover:

- Questions concerning the city
- On public transport (PT)
- On road network
- On Business Model idea

The questionnaire for the STP users should cover:

- Questions on personal data
- On travel habits
- On user opinion on traffic problems in his city
- On his interest in using Smart Travel Planner

3.3.4 What should future "business model" work focus on to support the adoption of autonomics in traffic management?

(Muna Hamdi and Barry Moore, iMFV Collaboration Group)

Investment Strategies

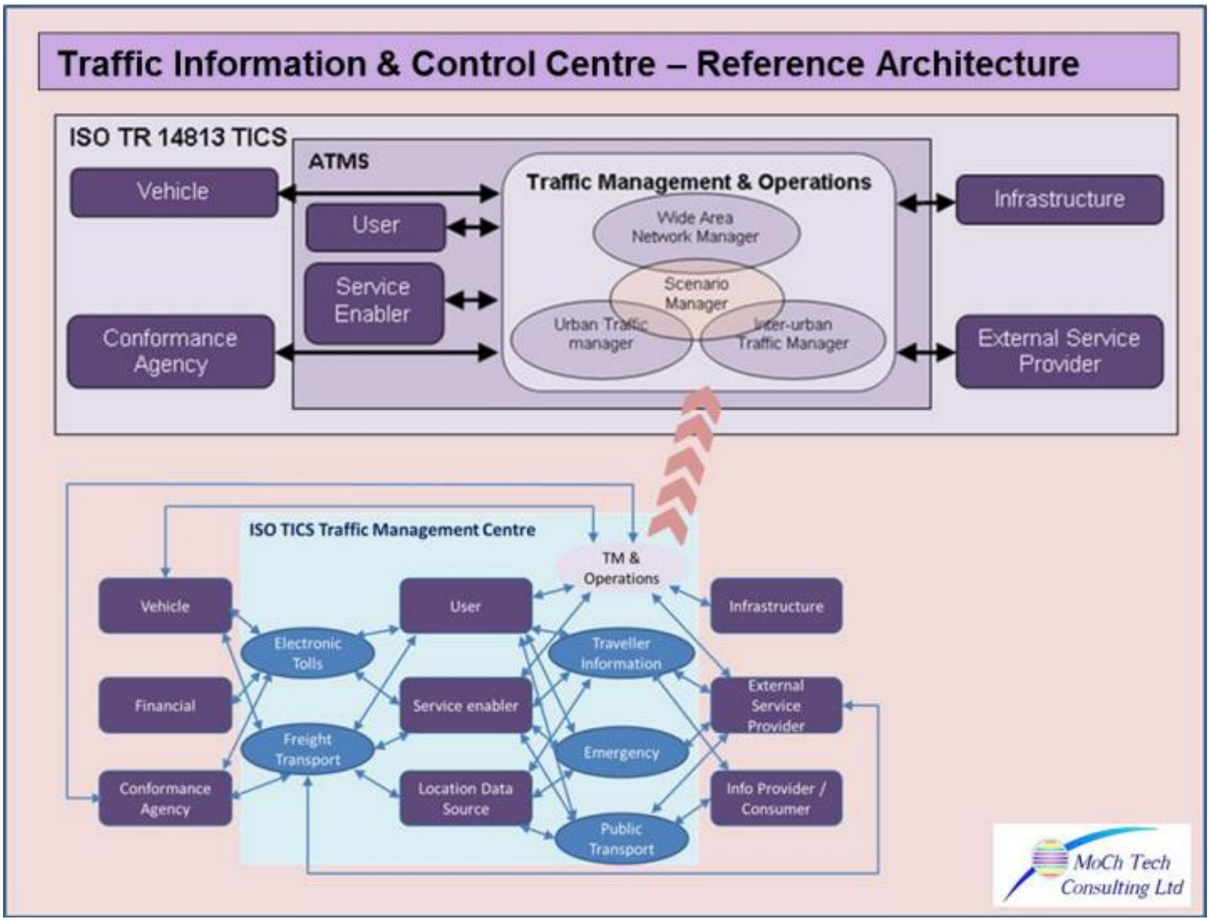
The business case and the model it forms a part of, relies on the route chosen to implement autonomics. There are several potential routes; viz.

- Extending the life of legacy systems with scenario management modules
- First time users – e.g. developing countries taking advantage of the embedded intelligence/capability in self-determining systems
- Replacing obsolete or time expired legacy systems – the "big bang" option of wholesale change to overcome limitations of conventional systemshe major players will be the owners of such systems. That is the traffic authorities and their future investment plans to improve services through improved ITS and the ITS industry being able to see that autonomics brings advantages and solutions to overcome their present challenges and therefore worth investing in the technology.

That leaves the open question: "which implementation route should we focus on to develop the business model around and improve the probability/potential for the adoption of autonomics to replace conventional computing"?

Legacy Migration

Currently, urban and inter-urban traffic management systems are mature but increasing demands for better traffic management suggests conventional computing is reaching a "complexity buffer".
There is a significant demand for interoperability between the two to provide a wide-area network management capability, further increasing system complexity.
One envisaged solution, see below, is the development of autonomic scenario managers to take on the additional burden of complexity. This should extend the life of legacy systems while bringing the benefits of self-determination to solve the increasingly complexity challenge.



Conclusion (Krasimira)

The development ARTS is a complex task which has to follow the main principles of the White paper on the Future transport, published in 2010 by the European Commission. It has to reflect a set of requirements about future transport vehicles, which have to be not only intelligent but with lower emissions, so that to be fulfilled the severe restrictions related with the environment protection. Many institutions like European Commission, EU governments, regions, cities, industry, social partners and citizens are responsible for realizing this ambitious goal. As there is a difference between East and West European transport network, the future actions have to be integration and globalization of the designed transport programs, plans, services, and information systems. The usage of combined mode of transport including air, road, train, river and maritime transport in order to satisfy the travel and freight customer needs is a desirable tendency. The future autonomic transport systems have to be designed in a manner of satisfying a movement in efficient and optimized manner according to the vision of EC on the future transport. Researches and implementation of “pure” fuel (alternative sources of fuel, electric power supply systems, available in the cities) is one of the development directions in order to protect the climate on the planet. Another actual topic is decreasing the congestions in the cities, which are the main source of air and noise pollutions caused by the transport. That is why the researches on this topic are intensive and the modeling target is decreasing the traffic congestions which do not have only travel aspect but environmental as well. The autonomic road transport system makes its first steps realized by leading world transport companies which began producing driverless cars implementing in them many automation circuits. The problem of human factor in these transport vehicles is a topic of discussion with a predominate vision of necessary human presence (according to today’s point of view). The principles of automatic control are applied in the modern transport vehicles and their future application will be wider and deeper in order to integrate the systematic engineering approach, decentralized approach, hierarchical and coordination principles in order to satisfy the autonomic properties.