LUT-UNIVERSITY

LUT School of Energy Systems

LUT Mechanical Engineering

ADVANCED ROAD TRAFFIC MANAGEMENT SYSTEM

KEHITTYNYT TIELIIKENTEENHALLINTAJÄRJESTELMÄ

Lappeenranta 5th of October 2019

Tapio Välikangas

Examiner D.Sc. (Tech.) Kimmo Kerkkänen

Supervisor D.Sc. (Tech.) Kimmo Kerkkänen

Contents

TIIVISTELMÄ

LUT-Yliopisto

LUT Energiajärjestelmät

LUT Kone

Tapio Välikangas

KEHITTYNYT TIELIIKENTEEN HALLINTAJÄRJESTELMÄ

Kandidaatin työ

2019

69 sivua, 36 kuvaa, 1 taulukko

Tarkastaja: TkT Kimmo Kerkkänen

Ohjaaja: TkT Kimmo Kerkkänen

Hakusanat: Automaatio, Hinnoittelu, Konedynamiikka, Robotit, Smart City, Säätötekniikka, Tekoäly, Tietoliikenne

Työssä määritellään tieliikenteen hallintasysteemi, joka ehdottaa itsenäisesti toimiville ajoneuvoille ajoreitin omalla alueellaan, ja hinnoittelee sen. Alueen koko on hallintasysteemin sensori- ja kameratolppien välillä oleva tien osa, ehkä 100 m. Sen toimintaa kuvataan yhdessä ajoneuvojen kanssa. Näistä muodostuvan liikennejärjestelmän ominaisuuksia arvioidaan eri eturyhmien osalta.

Liikenteen keskeiset toimijat nimetään ja hallintasysteemin vaikutus eri ryhmiin tuodaan tarkasteltavaksi. Nimettäviä toimijoita ovat tien omistaja ja ylläpitäjä, hallintajärjestelmän vastuuyhteisö, lain säätäjä, liikenteessä olevien ajoneuvojen haltijat ja omistajat, sekä vakuuttajat.

Hallintasysteemin määrittely dokumentoidaan systemaattisesti ns. Systems Engineering konseptia käyttäen. Painopiste alueita ovat toimintaympäristö, toiminnot ja järjestelmän vaikutusten arviointi. Teknistä toteutusta arkkitehtuurin tasolla, sekä tietoliikenneratkaisun ominaisuuksien kuvausta.

Määritellyn systeemin vaikutuksia selvitellään liikenteen ominaisuuksien muutoksen kautta. Liikenteen energian tarve ja hiilidioksidin tuotto selvitetään. Järjestelmän vaikutusta liikennöinnin tehoon ja turvallisuuteen, sekä joustavuuteen käsitellään.

Liikenteen taloudellisia arvoja käsitellään, ja arvioidaan järjestelmän toteutukseen liittyviä asioita. Etsitään järjestelmälle hintaluokka. Siirtymäajalle perinteisestä liikenteestä hallintasysteemien ja itsenäisten ajoneuvojen pääosin muodostamalle liikenne virralle annetaan aika-arvio.

Yhteenvetona huomataan, että järjestelmän voi yleistää kaikkiin tuotteisiin ja palveluihin kohdistuvana ehdotus ja myynti palveluna, joka toteuttaa smart-city konseptin. Se on myös tekijänä liikennöinti moodien kehittyessä.

ABSTRACT

Lappeenranta University of technology

LUT Energy systems

LUT Mechanical engineering

Tapio Välikangas

KEHITTYNYT TIELIIKENTEEN HALLINTAJÄRJESTELMÄ

Kandidaatin työ

2019

69 sivua, 36 kuvaa, 1 taulukko

Examiner: D.Sc. (Tech.) Kimmo Kerkkänen

Supervisor: D.Sc. (Tech.) Kimmo Kerkkänen

Keywords: Artificial intelligence, Communication, Machine dynamics, Pricing, Robotics, Smart City, Simulation

The study describes an advanced road management system delivering suggestions about the route in the domain of one subunit. It also does pricing on the lane time. The length of the domain is about 100 m, i.e. the distance from one street pole to the next. Poles are for cameras and base stations of cellular communications traffic. The operations of the traffic management system are described together with an autonomous vehicle. These systems form a trafficking entity. Properties and effects of it are described.

Principal groups of road trafficking are named, and the effects of management systems on each group are observed. Groups are mentioned: owners of the road, maintainers of the road, maintainers of the management system, regulators of the traffic, owners of vehicles, holders of vehicles and insurers of people and traffic.

The management system is presented with the Systems Engineering concept used in the U.S. Department of traffic. First traffic in the U.S. is presented, then operating system concepts, and the architectural solution is explained. The level of description is defined by the expected size of the study. Some description of communication technologies for the system is in the study. Properties of the peer to peer, Client Server, and hybrid network are briefly described. It is one of the primaries of the management service.

The effects of the system are elicited from the changed properties of the trafficking. The operational system is evaluated for efficiency, safety, and flexibility. Energy consumption and CO^2 production of road traffic are brought up.

Also, some financial aspects are evaluated. The price class is sought after, and the transition period from conventional traffic to an automated one is estimated.

As a conclusion of the study, a remark about generalizing the system to cover every product and service in the market is made. The Smart City Concept is compared to the generalized system. Also, the effects on trafficking modes are under observation.

VARIABLES AND NOTATIONS

ATMS – An Advanced Traffic Management System. A system with the capacity to deliver a detailed and safe path for vehicles.

AV – Autonomous Vehicle

COG – Center of gravity

CV – A conventional Vehicle

DCF – Discounted Cash Flows

DOF – Degree of freedom

FHWA – Federal Highway Administration

GPS – A global positioning system, satellite navigation

HOST – An ATMS unit actively connected to an AV via a cellular connection

IMU – Inertial measurement unit

IR – Infra red

LEAF – A node in a net construction, without children

LiDAR – Light detection and ranging (a laser-based distance measurement device)

PITCH – Rotation with a nose-down–nose up phase, Z-axis

RADAR – A device transmitting high-frequency radio waves and receiving reflected.

ROLL – Rotation orientation axis in the forward direction.

RTMS – Road Traffic Management System

TMS – Traffic Management System

US_DOT – United States Department of Transportation

V2V – A Vehicle to Vehicle communication

WACC – A Weighted Average Cost of Cash

YAW – The rotation around Y-axis, i.e. lateral rotation around the vertical axis

1. INTRODUCTION

A Traffic Management System, TMS, is an automatized system to guide the stream of traffic on the domain it has. The emergence of autonomous vehicles, abbr. AV has made it possible to develop a higher level of traffic guidance systems. Systems that can show a free path on the street. They are also capable to handle pricing schemes for the use of resources, like roads and power. An Advanced Traffic Management System ATMS collects and delivers money from clients to providers, and sometimes form providers to clients.

Primary classes of the trafficking are providers and clients. Some groups of providers are:

- Owners and maintainers of the road
- Owners and administrators of an ATMS
- Insurers of the people and vehicles
- Regulators of the traffic

Individual vehicles are clients. Provider – Client relationship implies two systems with own sets of Degrees of Freedom, DOF, for each. Some of the DOFs of different systems are connected. They require information exchange between ATMS and AVs. The connectedness enables the combined system to perform. Private DOFs allow systems to operate without the creation of systemic tensions.

An ATMS and an AV have own identities and domains of operation. They co-operate to provide improved safety and performance for vehicles and better utilization of the road system. The combination of systems also makes it possible to circulate finances from clients to providers, utilize regulations, and deliver elaborately real-time information of the traffic.

The need for government funding on the street resources can be replaced by regulated private companies, allowed to tax each vehicle-mile driven on the road.

An ATMS allows subsidizing the road system in a vehicle by vehicle basis. One group is getting different level of support compared to another. The pricing of the lane mile and the share coming from the government is individually changeable, just like taxation of freight traffic is different from taxation of personal traffic.

The study recognizes, how subgroups of providers might receive individual services from an ATMS. The maintenance of the roads and the administration of trafficking management are likely to be handled by different companies. The same is true for insurers. One share of the price of insurance is vehicle oriented, and the other depends on the road and time.

Transferring from Ordinary vehicles to AVs takes tens of years. First versions of AVs must be fully capable to proceed without the presence of an ATMS, and the threshold to reach valid trafficking is higher, if compared to generations connected to an ATMS. Also, some TMSs are not in the position to provide detailed driving properties of an advanced solution. This is due to the proportion of OVs in the beginning. Most of the traffic is driven by people, and a detailed level of guidance is between machines.

The study is oriented to street trafficking from interstate highways to minor connectors in suburbs. Metropolitan areas and the traffic on rural roads are similar at a fundamental level, and they are implicitly within the domain. The parallel installation of the system is supposed to fit on 50 lane highways of China, as well as in the future traffic near metropoles of unlimited size.

Traffic management systems are affecting almost every logistic mode: Air traffic, railroads, and ships on the sea. The road traffic is the main orientation of this study. New solutions enable it to have properties of trains and airplanes. Adding to that, road trafficking has one major edge over others. It is a door to door service.

Drone traffic is adding new features to logistics. Most minor transportations are viable for the services of them. A little army of flying machines may serve better than others for food deliveries and other light transportation needs. Drones are going to require a management system in conurbations. It is possible to include them in the generalized version of an ATMS, but this version of the study is not handling it.

The diversification of the ownership of the vehicles is getting a share of the interest. Instead of maintaining and owning the vehicle, people are renting each trip from a providing company. It is a consequence of metropoles growing, and a change in the role of a driver from a person to a machine with intelligence. Higher densities of the populations promote higher utilization of the space and vehicles. Hailing services and taxi companies, renting AVs for individual trips, are expected to increase their share in personal transportation. This is partly because of the higher price of the parking space in metropoles. (Statista_FUEL 2019; Polytechnique Montreal 2018).

A robot as a driver of the vehicle makes the ownership of the vehicle potentially less personal. It is not so strongly part of identity. If the passenger is not addressed to drive, the association between the vehicle and the traveler has a passive nature.

1.1 Objectives of the study and the research question

The integration of services and information systems is an ongoing trend today. It has expressions in the Internet of Things, abbr. IoT, search engines, and social media.

Trafficking is also changing. Autonomous vehicles are going to change the structures of daily life. The development of road traffic management systems, autonomous vehicles, and intelligent city concept are reaching the level when logistics doesn't require human interventions, except for supervising and maintaining the process.

The objective of the study is to find an opinion on how road trafficking is going to develop until 2050 and thereafter. It is observed by studying today's traffic in the lab called the U.S. By utilizing the potentials of technologies of the day and observing the needs of traffickers, and people in general, a plausible solution is sought for. The economic properties of trafficking are studied also. They provide the framework for developments in the communities.

Effects of an Advanced road Traffic Management System, ATMS, are observed and scaled with the U.S. road systems. They provide for the study a measure of volumes of construction, prices of implementation, and a scale of ICT processing. The U.S. version of taxation is also under some attention. It could be handled via an elaborate service provider of traffickers of the roads.

The development of ICT-technologies is creating fundamental improvements in resources and services available to people. Links between clients and services are getting faster and more economical compared to present levels. The study aims to exercise newish resources to produce new services and to develop a reference for observing an developing the infrastructure of trafficking.

1.2 The structure of the study

IMRAD is used for organizing the contents of the study. First an Introduction. Then in Methods, a Systems Engineering approach is presented and followed by the literature review. It begins with a presentation of basic textbooks and online university lectures. The section continues by summarizing a study made by McKenzie about developments in the auto industry. Another terrain trafficking mode, railroads, are presented in a white paper made by representatives of 18 of active railroad companies in the EU. Papers have a perspective set to trafficking in 2030 (McKenzie 2015; Railfreightforward, 2019). American and European standards on intelligent trafficking systems, ITC, are briefly introduced. And sources of statistical information on trafficking are mentioned.

The Results chapter describes the operating environment of trafficking today, and it presents interest groups of the Traffic Management Systems. Next, concepts of Traffic Management are explored, and potential benefits of the systems are presented. Domains of an ATMS – AV combination are explained with description of basic functions. The description of fundamental components of an ATMS is in the study, but it is not trying to be detailed or complete.

In the discussion chapter some properties of trafficking, made possible by advanced traffic management systems, are presented. The potentials of CO^2 free trafficking are presented with the evaluation of an environmental load caused by a fuel-based traffic.

Conclusions have two subjects. The smart city concept is admitted as an analog to generalized service hailer, an upgrade of an ATMS.

The role of logistics is changing due to automation in warehouses and on roads. Price levels and response times of services associated with trafficking are improving. This is considered with the sizes and densities of populations on earth. Metropoles and services available to people are developing.

2. PRESENTATION OF THE METHOD AND RESULTS OF THE LITERATURE RESEARCH

The Method for documenting the solution in chapter 3 and the structure of the same chapter is similar with the Systems Engineering design practice shown in figure 1 (US DOT_trm_I101_SEP 2019).

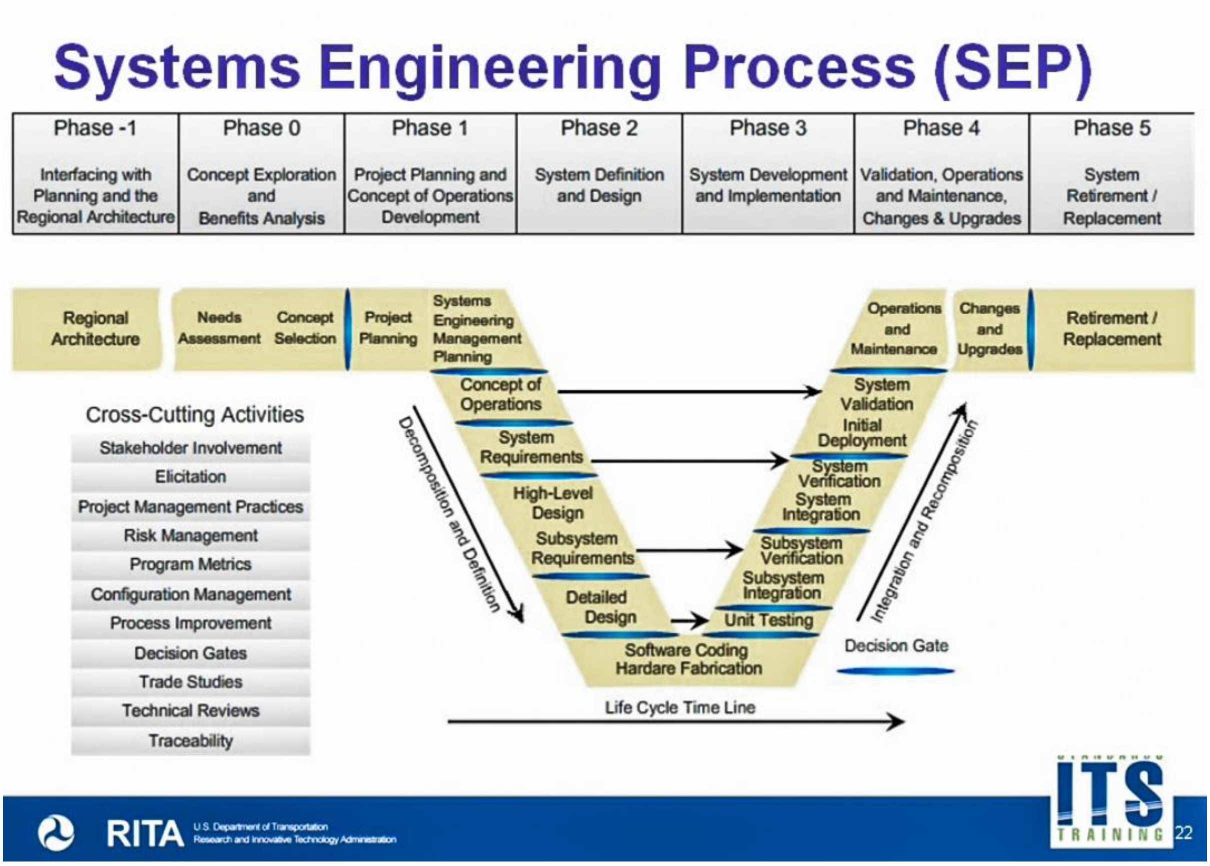


Figure 1. Systems Engineering Process shown here is used in many systems development projects.

The study implements phases -1 to 2. Phase 2 is kept within the scale of the study. Phases 3 and 4, implementation and maintenance, are part of the discussion, but they are not objectives of the study. Phases 4 and 5, upgrading and replacing, are considered as a part of standard business practices. Most relevant parts of the diagram in figure 1 are listed below:

SEP phase	***Subject in the context***
-1	Regional architecture of the road traffic. Participating people
0	Needs assessment of the road trafficking. Concepts of an ATMS
1	Concepts of operation. What the system does
2	System definition and design. Main components of the system
3	*Implementation*
4	*Maintenance and upgrading*
5	Next-generation or renewal of an ATMS

2.1Literature review

This chapter is to provide reading material about subjects activated by the solution of the study. Sections 2.1.1 to 2.1.3 is about state of the art in AI, deep learning, communication technologies, simulation, and vehicle dynamics. Sections 2.1.4 and 2.1.5 are to provide information about studies on the future of trafficking up to 2030. 2.1.6 presents the results of studying standards on Intelligent Transportation Systems ITS.

2.1.1 Vehicle dynamics and chassis properties

Vehicle Stability is a well-known book by Dean Karnopp. In 317 pages it explains fundamentals of vehicles, like Pneumatic tire forces, the stability of trailers, Inertial frames, cornering. The slip angle of tires and stability of over or understeer conditions are defined. It has also a chapter about dynamic stability control systems used in the early years of the century. The book is printed in 2004.

Chassis Handbook by Bernd Heißing and Metin Ersoy is a book about Fundamentals, Driving Dynamics, Components, Mechatronics, and Perspectives. In 579 pages it covers technical solutions used in chassis of vehicles. Also, the dynamics of the drive is covered. The book is dated 2011. Some topics are

- braking, and steering by wire, without direct mechanical link from driver to the actuation of the control
- driver assistance systems
- Stability control systems
- Active suspension technologies

2.1.2 Artificial Intelligence

For an introduction to neural networks, it is possible to study a free book at neuralnetworksanddeeplearning.com. It is only accessible with an internet browser because the pdf version doesn't support interactive features of the book (neuralnetworksanddeeplearning.com 2019). Massachusetts Institute of Technology has an open courseware material about topics of artificial intelligence. Lecture series "MIT 6.S191: Introduction to Deep Learning" is a good starting point for the topic. The material is accessible from (MIT 2018). Stanford has produced a lecture series Stanford Lecture CS231n about convolutional neural networks (Stanford 2019).

2.1.3 Autonomous Vehicles.

Autonomous vehicle control using a kinematic Lyapunov-based technique with LQR-LMI tuning (Alcala & al 2018) provides one approach to the control of the automated vehicle. Writers state about Lyapunov stability being a standard for nonlinear systems. They propose a controller based on the theory.

Designing optimal autonomous vehicle sharing and reservation systems: A linear programming approach (Ma & al 2017) is interesting for the study by presenting a reservation system for an autonomous vehicle sharing, a resource to improve a taxi service. It is an analog to a Lane Market renting the lane time for vehicles. The main concept is similar with an ATMS, but the solution is different, because of the differences of the associated parties.

Linear programming used in the (Ma & al 2017) is considerable for implementing a lane market. Another property of the Ma paper is the notion of an autonomous vehicle being more suitable for sharing, compared to traditional household vehicles.

Algorithm and hardware implementation for visual perception system in an autonomous vehicle: A survey (Weijing & al 2017) is a superficial presentation of some hardware implementations in the field. Technologies are only mentioned, and the interesting part is about the projects implementing them.

Autonomous Intelligent Vehicles Theory, Algorithms, and Implementation (Cheng 2011) are one of the rare papers attempting to present the whole system, instead of one detail of it. Cheng has stayed in solutions for the vehicle. Traffic as one entity is not in the main interest of his paper.

Autonomous Driving Technical, Legal and Social Aspects (Maurer & al 2015). It is not much about vehicle solutions, it consists of articles about legal and social aspects of the emerging concepts of transportation.

2.1.4 Smart City concept

Three different terms are used about the concept. Toru Ishida and Katherine Isbister introduced the term digital city in the book about conference proceedings on the matter. (Ishid, Isbister K 1999). [Directly:] “The first publication on the subject matter is considered to be the book by Ishida and Isbister (Sikora-Fernandez, Stawasz 2016). The term has developed to Smart City and Intelligent city. Terms have different connotations, and they are used to differentiate from earlier systems to more intelligent ones. Tahir and Abdul Malek give the following definition to the term:

[Tahir and Abdul Malek (2016)] “Generally, a smart city is a high-tech intensive city that connects people, information, and city elements using new technologies and infrastructure to create a sustainable, greener city, competitive and innovative economy, and enhanced life quality.”(Polytechnique Montreal, 2018).

The use of City orientation in the context is questionable. Clients of connected services are reaching services from everywhere with one interface, an avatar, for example. The provider side of the service handler, i.e. the operating system of the computer, is independent from the city, only connected services are with city orientation.

2.1.5 A program to increase the modal share of railroad traffic in 2030

"Rail freight Forward" is a program started by European rail freight companies. Currently, 18 participating in the work. They have published a white paper called "30 by 2030 – Rail Freight strategy to boost modal shift" to collectively inspire the industry to increase the market share of rail freight in the domain of European land freight. Projections are at a time negative for railroad traffic even if it is improving by freight-ton-kilometers. "According to macro-economic projections, European land freight transport will grow by 30% by 2030" (Railfreightforward 2019). Railroads have a modal share of 18% projected to decrease one percent. The paper gives also statistical information about freight traffic in Europe. Trucks 75%, boats 7% and a list of goods by volume with an estimate of rail affinity. After freight figures, they present strength factors of rail roads. Low energy consumption, and low CO_2 emissions because of that.

For a study about traffic management systems, especially road traffic systems, the white paper brings some primaries of trafficking in general. The modal development of trafficking is affected by changes in infrastructure, i.e. roads, tracks and associated systems. If the road system is upgraded with new lanes or organized to operate well with increased volumes of the future traffic, the position of truck traffic for keeping the modal share of the traffic would be improved.

An advanced traffic management system would have a significant impact on ownership, management, and development of the road systems. The white paper gives an observation about possible effects on the modal shares of trafficking. It also demonstrates the potential of highway trains, enabled by road traffic management. They save energy and deliver with one mode from door to door. (Railfreightforward 2019)

2.1.6 Future developments in road traffic until 2030

Another paper whose perspective is set to 2030 is produced by McKinsey & Company. The subject is about future developments in road traffic. It is published in 2016 and it emphasizes the business manager's interests on the subject but has technical considerations as well.

McKinsey gives a 30% increase to the absolute value of personal road traffic industries. Same number is given for the increase of land freight transport in Europe by European railroad companies. Few similar figures of the development:

- Estimated world population in 2030 is reaching 9 billion, if the linear trend of one billion increase in 12 years continues. With today's population of 7,7 billion, it would mean 12% increase in population. (UN_WPOP 2019; Statista_WPOP 2019). By exercising second degree of population increase, the result would be in a range from 25% to 28%.
- Riskless rate of 2,2% would give the result of 30%. When it is used to evaluate dollar value of the business, a steady state in the industry suggest.
- The freight volume is measured with ton miles, and The U.S. freight volume is forecasted by (Statista_TONMLS 2019) to increase about 30% by the year 2030. The forecast is based on the linear trend and is not considering economic problems before 2030. (US_DOT_FREIGHT 2018)

McKinsey paper has selected four explaining variables for the developments in trafficking:

- **Shifting markets and revenue pools.** Orientation is in the increase of the revenue in the automotive industries. The estimate is 1.5 trillion in 2030. Other factors are cointegrating with this one to some measure.
- **Changes in mobility behavior.** The increasing size of metropoles and cars without a person driving them is expected to increase the share of hailing and taxi services. It is a highly localized phenomenon occurring mainly in larger cities. The proportional share of those is increasing.
- **Diffusion of advanced technology.** How fast markets adopt vehicles driving autonomously
- **New competition and cooperation.** New companies producing solutions for new technologies. The map is reorganizing

The final chapter is titled with "Moving forward: How automotive players should align their strategic priorities"

- Prepare for uncertainty:

  The industry is about to change, hence the uncertainty.

- Leverage partnerships:

  New technologies are handled by new or specialized companies. To stay in the business, new partnerships are probably needed

- Adapt the organization:

  The organization of the company often has some symmetries to the organization of the industry. The change in both is anticipated

- Reshape the value proposition:

  The market is changing, and new products are entering the field. Incumbent companies should keep their value proposition, i.e. competitive edge to clients, up to date.

The last paragraph of the paper positions it as reading material for people of incumbent players of the automotive industry.

The problem in the paper is, it has no concept of Traffic management systems. It is probable, they start to get some role in the industry before the year 2030. And gain a real boost after reaching a critical size to serve major functions they are good for.
(McKinsey&Company 2016)

2.1.7 Smart Cities and Integrated Mobility, a white paper

For ITS World Congress 2017 in Montréal a group of students, postgraduate students, and a professor created a white paper about smart cities. It is a meta-study about smart cities, studying the literature and opinions of the people acting on the business. Technologies are not in the scope of the white paper, but motives and drivers. It emphasizes mobility over other aspects, like the smart economy, smart environment, smart living, smart governance. Students have surveyed five cities as case studies. The study is structured into the system of four dimensions:

- Driving forces
- Main strategies
- Implementation obstacles
- Impact measurements

Each dimension has three subs:

- literature research
- In-session interactive study about five cities
- web research.

The concept of the smart city is familiarized with the paper, but it doesn't reach into the future, except on a meta-level. Two quotes from the future section of the paper may show the attitude of many surveys. They are merely reporting, what others have said, then synthesis and conclusions. The first quote is from "key findings from the literature"

[direct quote] “Relating to the far future, the most frequent keywords are shared and autonomous. A change will likely occur concerning who owns, operates and uses the vehicle.”

The second quote is from “7.2 Results and analysis of the web survey and in-session interactive survey” [direct quote] “There is a consensus that technological advances are a pillar for future mobility. A city should be connected, the data open, but one should not forget that a city must also be livable and safe.”

Figure 2 is from the same chapter. The result of the survey on the main drivers of future development is mobility, open data, and Sustainability. (Polytechnique Montreal 2018).

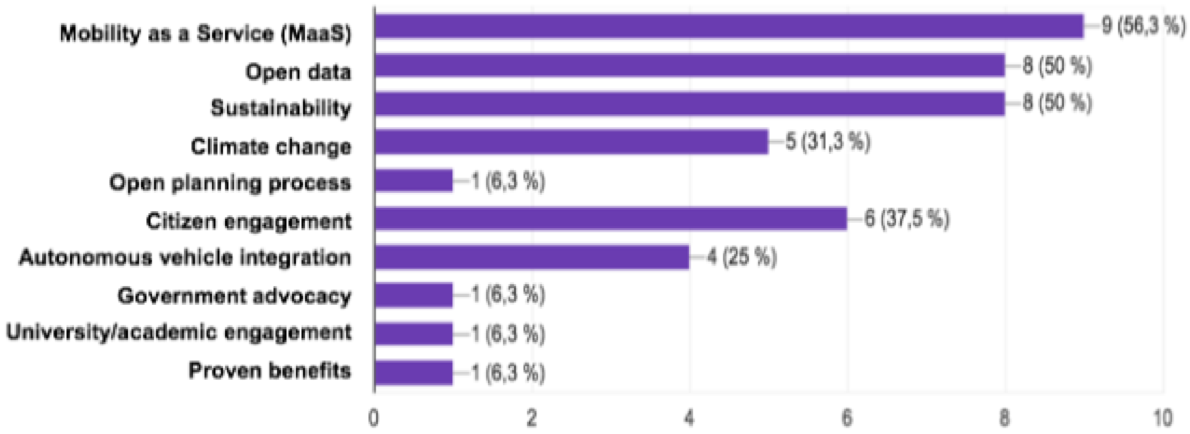


Figure 2. Results of In-depth survey about drivers of the smart city development. (Polytechnique Montreal 2018)

2.1.8 An ITS architecture

The presentation of the possibilities of an ATMS is aligned with the ITS architecture. It is possible to say: “A definition of an ITS architecture is a floor plan of an ATMS”. A quote from Richard Bossom below defines what the architecture does, it is not the architecture. The design, i.e. architecture of an ATMS, should conform specifications below, to be complete.

[direct quote] “An ITS Architecture is a conceptual framework (or structure) to guide the deployment of ITS. It is a formal specification of requirements that define in detail:

- the functions to be performed by the ITS deployment (the user services – such as travel planning, traffic and emergency management, road pricing)
- the physical components needed to deliver these functions (such as roadside equipment, vehicle-based control systems, control center workstations)
- the interfaces and communications necessary to allow an exchange of data and information between the physical components
- stakeholders' roles and responsibilities concerning the ITS deployment”

(World Road Association, 2019)

2.1.9 U.S. and European standards on intelligent transportation systems ITS

The standardization of systems and protocols suitable for traffic management is progressing in the United States, Europe, and Japan. ITS standards are still evolving, and there is a lot of upgrading until they can be used to fit ATMS's and AVs of different vendors together.

An American training material provided by U.S. DOT refers to IEEE standards. For example, IEEE 802.11 separates the communication part of standards to two main categories or layers of the communication stack. The upper, an application layer, is not directly dependent on the technical solution. It is about data structures and the selection of the transmitted data.
The hardware-related Media Access Control layer is depending on the hardware solution. and 5,9 GHz radio traffic. It is not usable, or economical, for the communication of every vehicle connected to an ATMS. A new 5G and proposed 6G cellular solutions are valid with fast switching and high capacity. They enable virtually continuous traffic with an ATMS. Frequencies of the lane trade are potentially fractions of a second. New solutions enable trading every meter separately if an unexpected change in the situation is requiring it.
Main areas for standardization are:

- A standard on the AV – ATMS traffic. Messaging between ATMS poles and AVs. Standards already exist, but they should be upgraded.
- Cellular trafficking practices. Already defined.
- Messaging between ATMS poles. Need's to be uniform within the segments, and preferably everywhere.
- The overall architecture of a Worldwide ATMS requires standards, if it is politically accepted.
- Details of Peer to peer networking in the context of ATMS. Connectivity of devices from different vendors.

(US DOT, 2019; JSAE, 2019; CEN, 2019)

2.1.10 Statistics about traffic, energy and climate

Almost every country collects statistics about issues of interest. People travel and buy products to be transported. Material and financial flows are measured to make the information available for people active on areas like the research and development segments of governments, businesses, academia and others.

Most statistics in the study come from Statista and U.S. Department of Transportation, also Federal Reserve Bank delivers a lot of relevant material, but it has not been referred. Statistics about CO_2 emissions and climate are from National Oceanic and Atmospheric Administration NOAA, an U.S. government agency (Statista 2019; US DOTb, 2019; Lindsey 2019)

3. RESULTS. AN ADVANCED TRAFFIC MANAGEMENT SYSTEM, THE DESIGN, OPERATION, AND OPERATING ENVIRONMENT

The study has two perspectives on trafficking. Qualitative and quantitative. A client in business is evaluating the value of quality measures. The price is in the other cup as a quantity. In the road traffic, new technologies would enable the funding as a compensation for the use of road.

The documentation in the chapter is based on the Systems Engineering Process, SEP. SEP phases from -1 to 2 are covered. To provide an environment for traffic management systems, some key factors of the U.S. road system are described in phase -1. China has today more highways, but U.S. data is used for historical reasons. In SEP phase 0 concepts of an ATMS are presented. A servicing ATMS is described in the SEP 1. SEP level 2 presents the net architecture and concepts of main components.

3.1 The road system

With the expense of constructing a mile of four-lane highway 4 – 10 million dollars, and the number of lane miles in the U.S. 8,61 million in 2016, would the construction of the road system cost from 10 to 20 trillion dollars.

Investments in the infrastructure are sizeable. About a trillion dollars a year (Statista_HWC 2019). The maintenance of Highways and street system is about 200 B $ yearly (PEW TRUST 2019), half of it is for the maintenance of highways. They are from one third to half of the expenses of trafficking depending on the year. The energy and vehicle expense are similar in the size (Statista_FUEL 2019; Statista_GPr 2019; Statista_MC 2019; Statista_AFT 2019). Together they are over ten percent of the GDP in the U.S. Trafficking is one of the four major areas for personal expenditure.

The road system is presently subsidized because of the convenience, i.e. practicalities, and because of the future value of the connectedness is considered valuable. New technologies are enabling flexible pricing of the roads, with or without subsidizing. Financing of the road system and maintenance of it is getting new forms. Even outsourcing the road system would be technically possible, but the nature of the market is prone to monopolistic developments. Creating a new road next to an overpriced one is sometimes a multifaceted issue.

To evaluate the value of the road, assets and liabilities would have to be priced. they are listed below, as generic accounts.

Assets:

- Throughput, maximum and average [vehicles / (lane x hour)]
- Predictability of the outcome i.e. estimated time of arrival
- Ability to serve different requirements of vehicles of the traffic
- The validity of payer – payee relation
- Safety

Liabilities:

- Price of the capital tied to the infrastructure
- Maintenance costs

3.1.1 U.S. Road system by the road types

[directly from FHWA_types 2019]"Over 164,000 miles of highways in the National Highway System form the backbone of our 4-million-mile public road network."

Since 1989 Federal Highway Administration has been grouping roads into three main classes. Figure 3 shows a schematic representation of road classes and mileage of constructed Interstate and other types of road types is constructed by 2008.

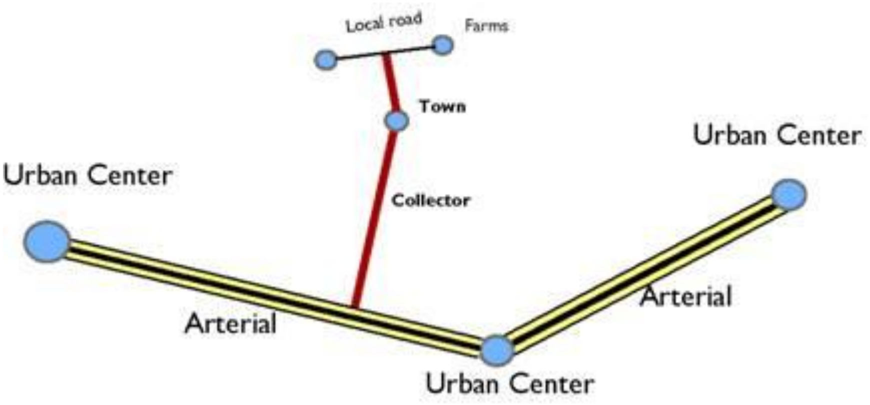
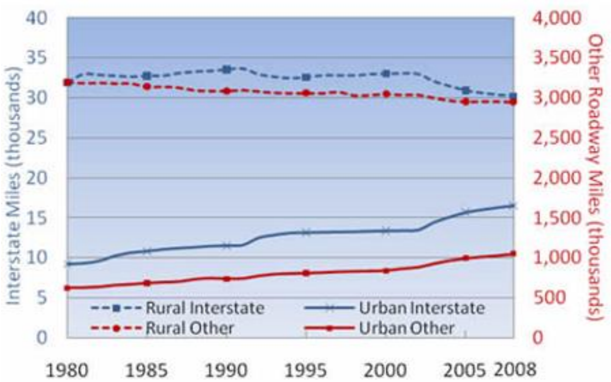


Figure 3. Three classes: Local roads, Collectors, and Arterials. (FHWA_types 2019)

3.1.1 Mileage driven on different road types

The mileage of driven miles on each road type is in figures 4 and 5. By evaluating densities of traffic annually the major role of Urban interstate roads is evident. From 3,225 trillion miles driven on 4 million miles of the road, Urban Interstate roads have 1.151 trillion miles driven on 9 thousand miles. It is about 128 million vehicles miles on a mile of the road when the average number is less than a million. Rural Interstate would be 32 thousand vs. 0,254 trillion, giving 7,9 million vehicle miles on the mile of the road. Rural other has 0,715 trillion on 3 million giving 283 000 vehicle miles on a mile. About 452 times less than urban Interstate.



Rural Interstate	254.1
Rural Other Arterial	376.7
Other Rural	338.6
Urban Interstate	569.1
Urban Other Arterial	1150.9
Other Urban	535.5
All Systems	3224.9

Figures 4 and 5. Miles of road types 40 000 miles Interstate highways 40 million miles other types of roads. (FHWA_types 2019; FHWA, 2019)

3.1.2 Use of the fuel taxes in the U.S. road system

Road trafficking in the U.S is based on over 4 million miles of roads. Rural and urban Interstate highways, freeways and other principal arterials constitute 222 689 miles of the road system (FHWA_FUNCT 2019). They are maintained by the government. A significant share of the funding, 80 B$ from 220 B$ in the year 2010, comes from fuel taxes. (Statista_FUEL 2019; Statista_TAX 2019; FHWA_revenues 2019). Sources of the revenue are shown in figure 6. Distribution of capital outlay, or share of revenue, on improvement and road types, is on the diagram in figure 7.

Source	Highway Revenue, Billions of Dollars						Annual Rate of Change 2010/2000
	2000	2002	2004	2006	2008	2010	
Motor-Fuel and Motor-Vehicle Taxes	$75.6	$73.1	$76.4	$85.4	$84.7	$84.3	1.1%
Tolls	$5.7	$6.6	$6.6	$8.3	$9.1	$9.6	5.3%
Property Taxes and Assessments	$6.1	$6.5	$7.5	$9.0	$9.0	$9.4	4.4%
General Fund Appropriations	$19.3	$20.3	$23.6	$28.3	$40.0	$58.6	11.8%
Other Taxes and Fees	$5.7	$7.5	$7.9	$10.1	$12.2	$12.2	7.8%
Investment Income & Other Receipts	$7.3	$8.1	$7.6	$9.7	$16.6	$13.9	6.6%
Bond Issue Proceeds	$11.3	$12.7	$15.8	$18.3	$20.9	$33.0	11.3%
Total Revenues	**$131.1**	**$134.8**	**$145.3**	**$169.0**	**$192.6**	**$221.0**	**5.4%**

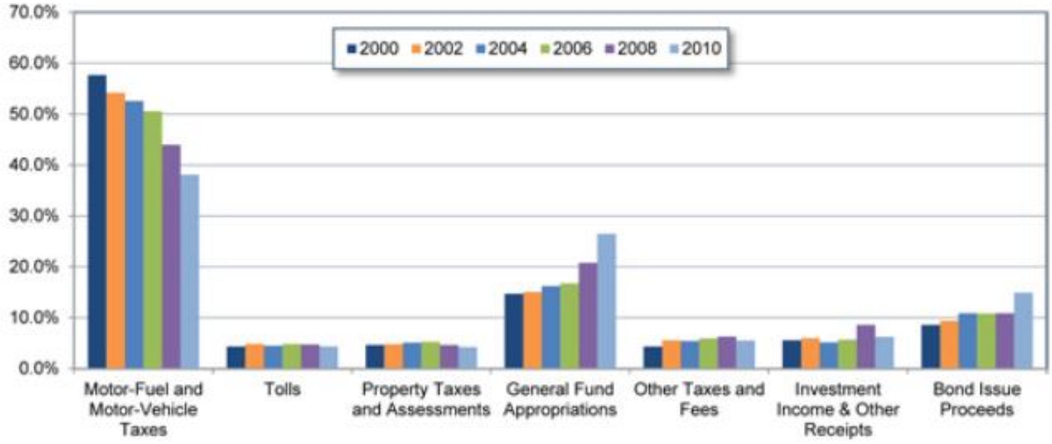
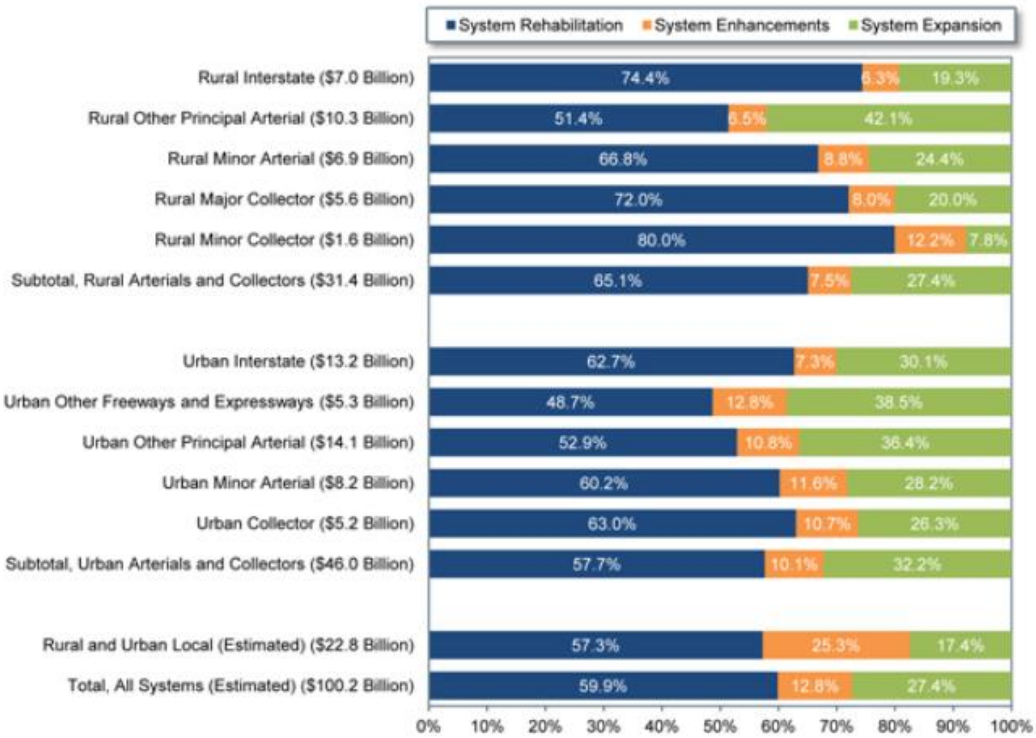


Figure 6. Revenues used by government on the maintenance highway system. (FHWA_revenues 2019)

Exhibit 6-13 Distribution of Capital Outlay by Improvement Type and Functional System, 2010



Sources: Highway Statistics 2008, Table SF-12A, and unpublished FHWA data.

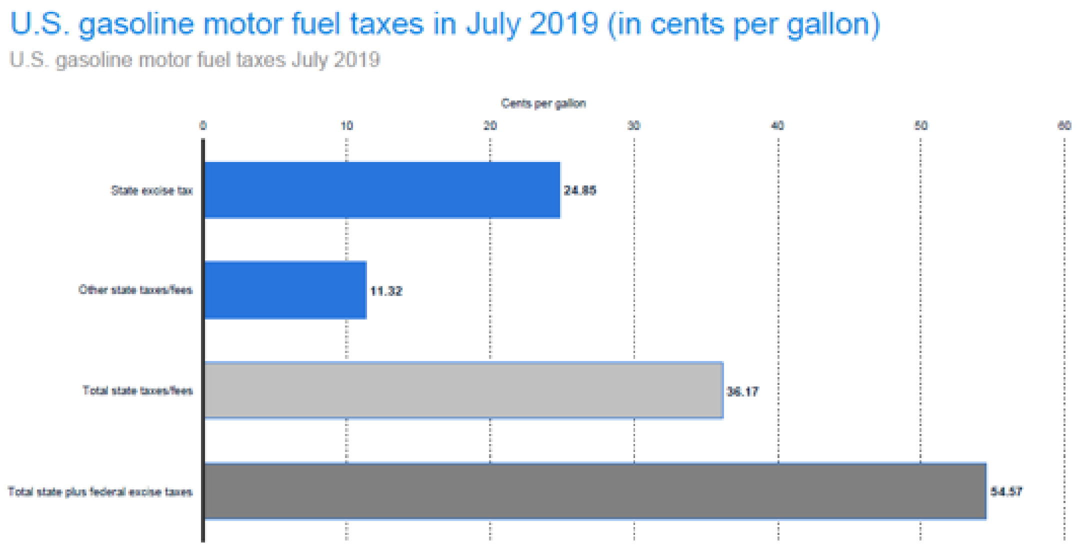
Figure 7. Distribution of capital outlay on renovation and road type. (FHWA_spread 2019)

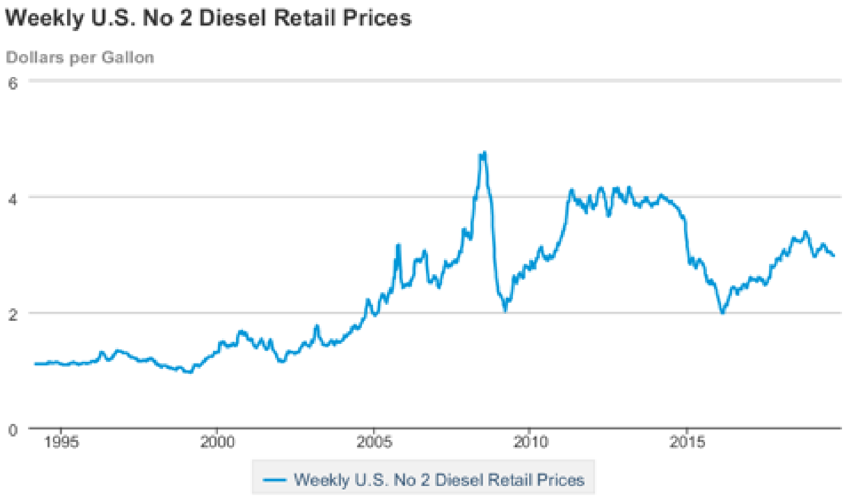
3.1.3 Energy expenses of the road traffic

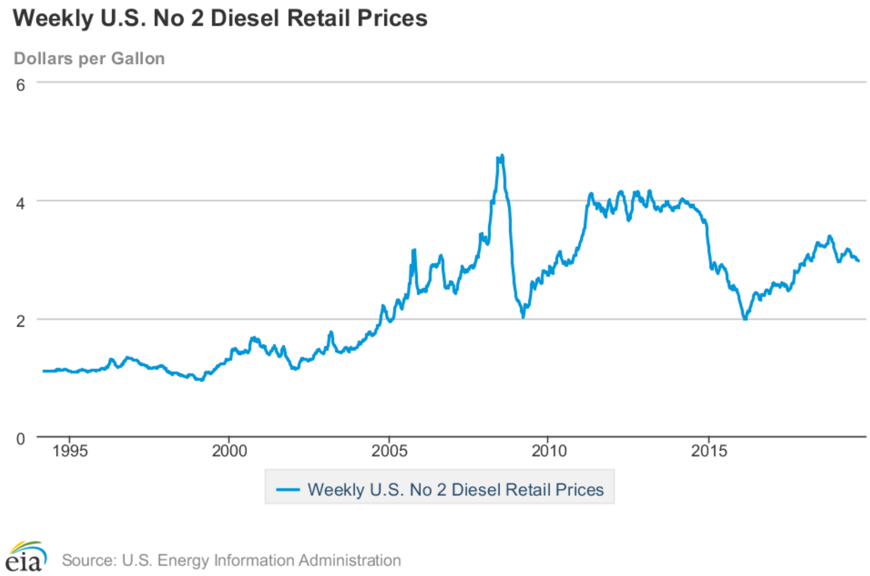
If capital flows of road trafficking are sized, energy is one of the three main groups. Gasoline and diesel expenses for road traffic are about 600 B$ in a year. (EIA 2019; EIA_PR 2019) The sum is derived from the retail prices of gasoline and diesel in figure 9. It includes about 84 B$ fuel taxes in levels of year 2010 shown in figure 6. Fuel taxes 2019 are 108 B$. (Statista_TAX 2019; EIA 2019). Price of fuels without taxes are about 500 B$.

Table 1. Consumption figures for 2017 from Energy Information Administration. (EIA, 2019)

Oil products consumed per day	M barrels	SI M m^3
Transportation U.S.	14.02	2.230
Gasoline U.S.	9.327	1.483
Diesel U.S.	3.632	0,577
All oil products U.S.	19.95	3.172
World	100	15.90



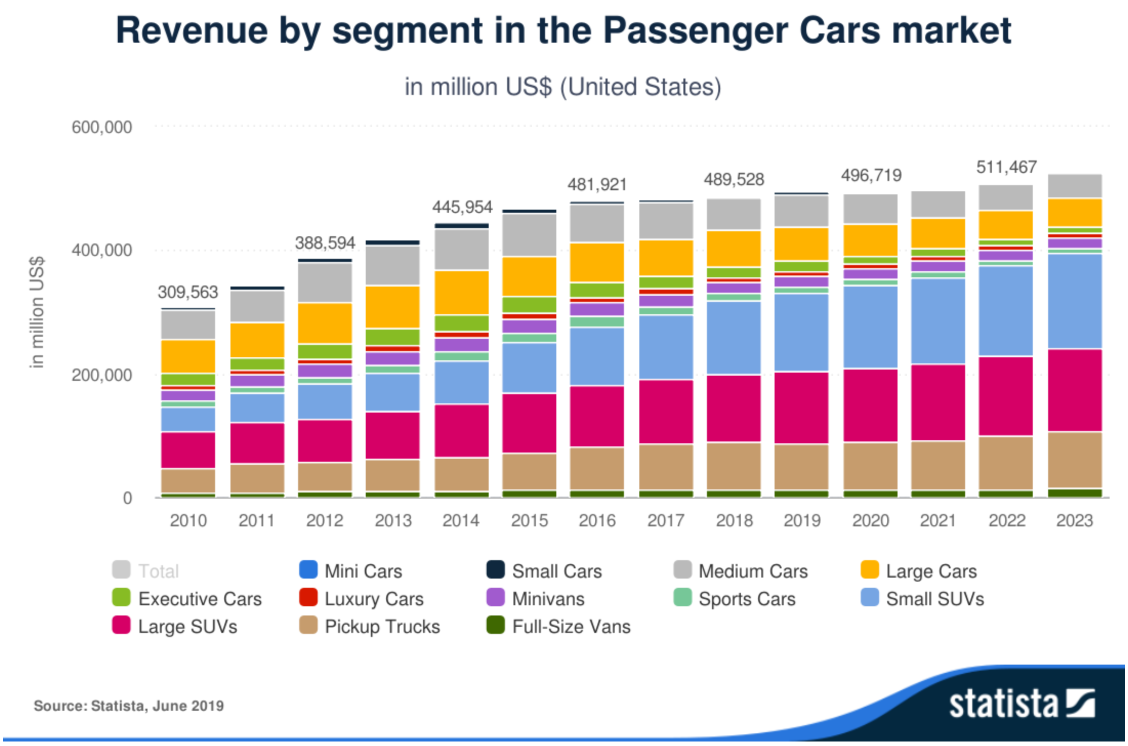


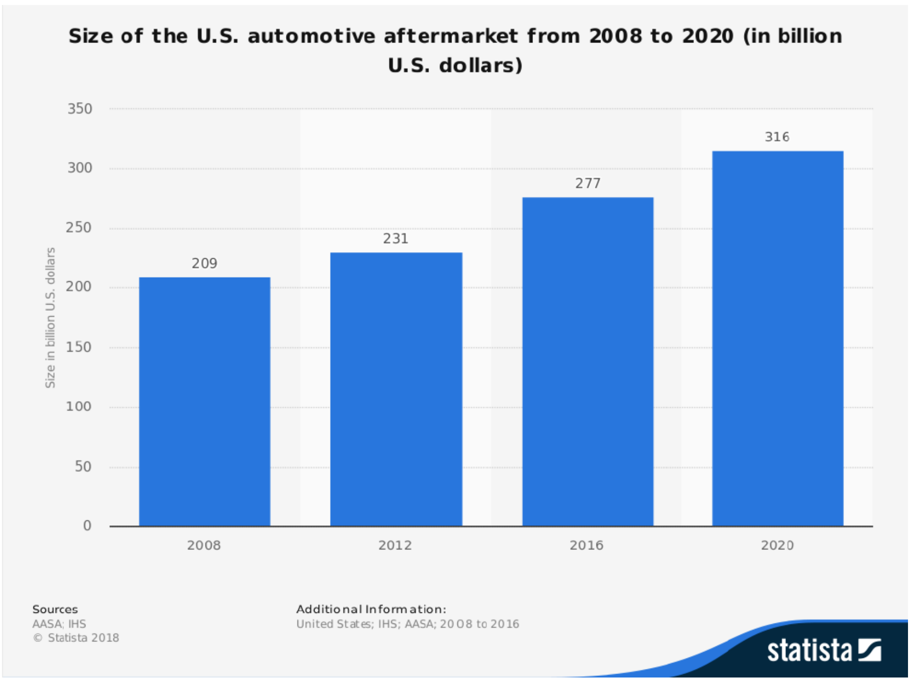


Figures 8 and 9. Taxes and Retail prices of road fuels in the U.S. (Statista_TAX; EIA_PR 2019).

3.1.4 Size of passenger cars market and automotive aftermarket

New vehicles and associated aftermarket are one of three big investments for travellers. In figure 10 is Revenue of passenger cars market by vehicle type. 500 B$ sets it to a similar size with fuel prices. In figure 11 is the development of aftermarket value from 2008. The year 2019 value is interpolated from the diagram with 300 B€. By adding it to car sales the industry receives 800 B$ in a year.





Figures 10 and 11. The car industry receives about 800 B$. (Statista_MC 2019; Statista_AFT 2019)

3.1.5 Road expenses

Road traffic expenses total over 2 trillion in 2018. The road construction is varying a lot from year to year. In average it appears to be similar with vehicle expenses. The statement is based on numbers in figures from 10 to 12.

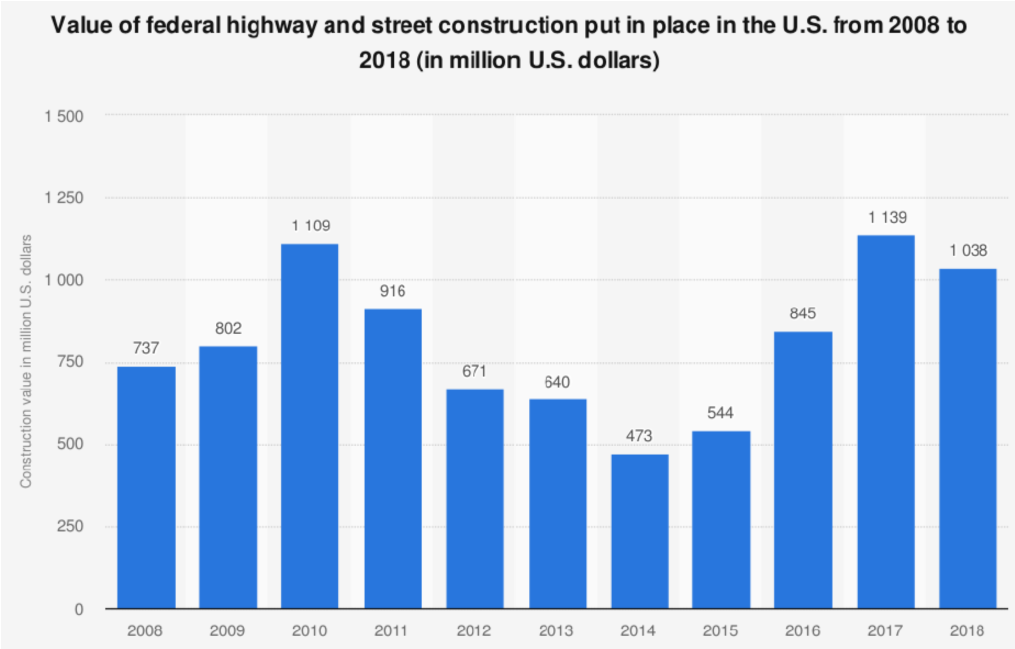


Figure 12. Value of annual federal street and highway construction. (Statista_HWC 2019)

3.2 Needs assessment. Concepts and benefits of an ATMS

Management systems generally improve manager's resources over the managed substance. The manager riding a horse is the provider and the controller of the resources, the horse needs. In the context of traffic management, the road is a resource, and the money is the service required for the road to exist.

General development in the functionality of the resources is like green stuff growing in the fields. Trafficking must develop with the density and volume of the population, for the wellbeing of the population to exist. It requires either more roads or some other ways to improve the capacities of trafficking.

3.2.1 Traffic Management Systems today

Today systems for managing, optimizing, and tolling of the traffic is mainly limited to interact via street signs. Vehicles are not equipped with connective technologies, except for some cellular phones for human drivers. Services inform traffickers about the weather, exceptional traffic conditions, and changing speed limits. Few toll roads are capable of bill owners of the cars for the use of the road.

An automated traffic control owned by the police has been in use for decades. It gives fines to speeding drivers, but it also requires some human intervention during the process. One example of implemented Highway Traffic Management systems is Compass, a Canadian system. (MTO 2019).

3.2.2 Domain of the traffic management organization today

Traffic management is a national business under the U.S. department of traffic. It handles trafficking issues at the federal level with Federal Highway Administration.

3.2.3 The difference of a TMS and an ATMS

An ATMS is different if compared to a traditional TMS of the day. A TMS interacts with the driver, while An ATMS has a connection to the information system of the vehicle. The response times and accuracy of responses are many times more efficient compared to responses of human drivers. Instead of an announcement about the traffic situation in the area to human traffickers, an ATMS provides information refined to a vehicle level. It has the present traffic situation and often accurate forecast of future traffic. This enables the pricing of the resources to promote balanced, i.e. efficient use of resources.

3.2.4 Primaries of an ATMS

A Rider stays with the horse to ride it. The bottom line is, an AV has the final word on driving decisions. An ATMS has information and ability to provide a valid drive plan. An AV has a responsibility to provide the drive.

The connection with a vehicle is key for the efficiency of the management system. The change in the role of management of the vehicle is changing from a person, i.e. driver, to the information systems of an AV.

The first generation, an AV, is riding one vehicle with one system. The next generation, an ATMS, is riding the traffic instead of one vehicle. It is required to create a bridge between the pros and cons of different travellers and providers of the traffic. It allows a higher level of integration between parties, and the responsiveness of the traffic is improved.

A traffic management system should optimize the properties of traffic.

- Safety
- Energy efficiency, less energy for the volume of traffic in time X
- Throughput of the road system, the volume of trafficking
- Response time from point A to B, speed of the trafficking
- Ability to make compensation of trafficking expenses synchronized with clients of the service
- Realtime information on details of the traffic

Safety is improved by improved responses to changes in the environment. An ATMS has an improved information level from an extended area compared to drivers of individual vehicles. The area of the trafficking is observed from the height of poles. Sides of the street and the lane are guarded. Awareness of other traffickers on the road is superior, compared to present trafficking.

Energy efficiency is evaluated with consumed energy for traveling time and transported load per travel. Higher speed in the environment of open roads consumes more energy. An improved safety level would allow notable elevations in speed levels. Also, ATMS technologies allow chaining of the vehicles, which would enable higher speed levels with similar energy. A refined map of elevations of road systems allows vehicles to have an optimized and active suspension system. It allows harder tires with less friction involved.

Chaining improves the throughput of the road system. On inner lanes, an endless chain of vehicles would require a fraction of the lane area compared to traditional vehicles. And they would drive faster. Robots are comfortable with 24 / 7 schedule, and transporting the cargo is likely to exist during the nighttime. The lane capacity would allow more people on the roads in the camper/office vehicles, and less in the airports waiting for connections.

Velocities of vehicles are potentially higher within an ATMS environment. The validity of the information about the road, weather, and animals with their flexibility of traffickers guided by the system would allow many times higher velocities on parts of the road. Response times would be priced factors of trafficking.

Ability to synchronize expenses with the use of services. Real-time shopping of lane time with price levels tailored to each client allows a milelong train to pay an improved price for the economy of the use of space, it would improve the position of the vendor of the traffic as well as the vendor of the road. Directing subsidies with individual precision is also a resource made possible with an ATMS.

Realtime information is a natural continuation of the system. Every vehicle on the domain is reachable in a fraction of a second. Attributes of the data to be reported are numerous. Vehicles with specific cargo, like fire trucks, or people driving to the area of interest, e.g. Olympic games, at specified time, would be listed. Regulation of rights for the data is on the domains of government and ATMS organizations.

3.2.5 The security, and the cyber defence

Trafficking is a one of the big four in national economies. They must be protected from the aggressions of other entities. A cyber terror, blackmail, or war would have a nation in a helpless state, if vehicles were randomly attacked. Security is one of main motivations to keep the final decision of actions locally in the vehicles. People in the ICT-security business know, limitations of reachable security level. It is as important as armies and the police force for the wellbeing of the nation, but price level must be kept in balance also.

3.2.8 A destination, a route plan, and a path plan

Few concepts describe the details of the journey. Initially, the vehicle is given the destination and time of arrival, or optionally a traveling style, the destination. A route, planned by dedicated service, includes every change of the road during the travel with estimated times. Refined route plans are made by road-oriented servers. They have information about on the traffic on the domain, i.e. the road, known so far.

Style and route are suggested either by the vehicle system, or an ATMS during the preparation phase. Systems negotiate to optimize the traffic and expenses with constraints implied by the holder of the vehicle.

3.3 An operational ATMS.

Description of operations is provided by describing functions of an ATMS as services available to AVs, holders of AVs, maintainers of the ATMS and other providers in the area of trafficking.

3.3.1 Services to AVs

Functions of AVs available as services of an ATMS are

- Observing the environment
- Producing detailed paths within the route
- Pricing different driving options

The system observes environment with video cameras, optionally with infrared for animal detection, a weather station, and network connections.

A weather station is required on every pole to make details of local weather conditions available. The ice detection must have a special solution to detect conditions near 32 ˚F, where rain turns to ice in a second. The main source of information is the communication with AVs, they update their whereabouts practically in real-time to the hosting ATMS unit.

An ATMS collects information from cameras in the same unit, and with peer to peer network from two layers of neighbours. ATMS units also collect information with client-server network connection from a wider domain. The unit keeps a database of vehicles approaching the inner domains of it. Vehicles on roads within a selected radius, called secondary, or outer, domain, and known route plans of them are kept in local units near them. The database is updated when a route plan involving the area is taken into, or created by, the ATMS. The information is verified and calibrated with the cameras of the system when the vehicle is arriving on the inner domain. Any changes are broadcasted to interested servers and neighbours.

Vehicles are supposed to be seen by at least four cameras simultaneously. With a communication link from one to another, they can combine the information to produce accurate information about the position and posture of the vehicle on the road.

To provide a real service to vehicles, poles have a surface profile of the road in their domain. Every stone and crack are known to it. Water, ice and snow on the lane must be known to the system. It has an adaptive algorithm for detected changes in friction levels. New elements like oil on the road would be learned by the system. If a similar event occurs again, vehicles know before touching, how it affects the driving conditions. Technologies, like radars for foggy, rainy or snowy conditions may improve safety in some environments.

3.3.1 The process of bringing the ATMS into the trafficking environment

The creation of an ATMS is a process. It has many owners, and it can't be dictated. If the developments in trafficking, economy, and technologies continue, the emergence of street automation develops with technologies of vehicles. First systems providing free lane time require vehicles to be capable to interact with the service. It is possible after manufacturers of vehicles have agreed on details of communication formats between systems. standardization processes have started and if results are accepted by the manufacturers, the construction could start. It will take tens of years until a major share of traffic is driven by the system.

3.3.2 A description of an ATMS in operation.

Optimization of the traffic is what an ATMS is for. It has information about planned whereabouts of vehicles. It creates predictability to the traffic and allows an ATMS to provide optimal drive plans for vehicles in the domain.

An ATMS must observe the traffic to map two sources of information, vehicles reporting through radio and 3-D cameras located on the poles next to the road. The reasons for this are reliability and safety. Cameras are needed to keep track of unregistered travellers, like animals and wild OVs. They are available for improving reliability when one system is giving false information or no information at all. If the information given from AVs to an ATMS pole is matching observations of the ATMS, it is assumed credible. The same is true for AVs. If a GPS, an ATMS, and information of sensors like an IMU-chip agree on the position, speeds, accelerations, and directions, the status of the system is set to valid.

The size of an ATMS core domain is the distance of base units from each other. When some unit of an ATMS is not in operation, it is replaced by extending domains of surrounding ATMS poles. A pole should be capable to serve neighboring domains as well. The redundancy in the capabilities is to provide extra robustness for traffickers. If some piece of the network is not servicing a neighboring unit covers the action. Vehicles are assumed to be capable to function independently as well.

An ATMS needs to compare movements of objects to anticipated behaviour forecasted with laws of mechanics and features of the object. AVs have less information about them. Poles of the ATMS system are connected to the server layer. They accumulate statistics about the features and behaviours of similar objects.

Unknown objects are identified as members of some group of similar type. It makes forecasting of trajectories, speeds, directions, and masses of objects more reliable. If an AV is not connected to an ATMS, it would have only the information, it can acquire and accumulate on the spot.

3.3.3 The formation of the path plan

The hierarchy of trafficking has two peaks. An ATMS sells safe lane time on the road, a path plan, and an AV stays on it, when possible.

For the creation of a path plan, an ATMS and an AV have similar abilities. Either of them must be capable to write details of the route. In rural areas, where the volume of the traffic is not buying an ATMS, an AV operates in the independent mode. It can communicate with remote service, which can inform about nearby vehicles. An AV can communicate with those using V2V protocols and continue autonomously proceeding in the local area.

When an ATMS is active on the site, it will propose each vehicle an exact path, it should be following. If the deal is not accepted by an AV, a re-trade is attempted, with the known reason for rejection. The shopping is done before the vehicle enters the lane area of the ATMS unit.

3.3.4 The market for lane time.

The process is advancing in two phases. When the vehicle has a route plan, it usually buys an option to travel with it in advance. If the option is not used, the system notices it, and only a nominal payment for the reservation is billed. Negotiating the real-time travel

During the travel, an AV is continuously buying free space on the road from the ATMS. The normal situation is to stay with the original route plan and adjust it if local conditions make it necessary. Before entering the lane area of an ATMS unit, the vehicle is asked, if it approves the suggested drive plan for the domain, which is about a hundred meters of the lane area. In critical situations, the length of the planned path is reduced, and a new plan is generated with higher frequency. The length of the plan is sometimes only a fraction of the size of the vehicle or the size of the domain.

3.3.5 Pricing of the route plan, the use of the road, and other resources

New technologies allow elaborate pricing of the resources. The construction and maintenance of an ATMS and the road requires money and resources. Often the pricing is based on the use of the resource, although it is in the interest of the government to enable some resources to be made and kept in use by subsidizing them.

The actual price is defined with the time value of the money, risk factors, motivations of regulators, and competitiveness of responsible parties. It is possible to have different owners and administrators for the road and an ATMS. The government is sometimes keeping the ownership of the road area, but the private entity is franchised with the right to tax users after building the system on it. The pricing is to favour road owners also.

The price level varies with the volume of the traffic. By selecting less crowded hours, or early shopping time, holders of vehicles receive better pricing of the lane time. In essence, an ATMS is pricing the lane space to improve trafficking conditions. If a busy vehicle would cause others to change their path plans, the price is significantly higher.

Terms of insurances of the traffic are often related to risk and price levels of the insured domain. It is an advantage for the insurer and for the client to be able to allocate expenses to the real causes of them. It promotes less hazardous behavioural patterns, and clients experience fees more justifiable. If the insurances of traffic are priced with the risk levels they are exposed to, they should be part of pricing system of an ATMS.

The price level of the trafficking is improving, because of the improved throughput of the road system, less human labour needed for the traffic, and safer ride for the vehicles. Traffic control is a part of the ATMS, and physical interference is generally not required.

3.3.7 The outlook of the traffic. General reporting and responding to ad hoc requests

A major benefit of an ATMS is to allow real-time access to the traffic situation. A client of traffic management can browse through the information if he is entitled to it. For example, a rental company has an allowance to buy access to the reporting of vehicles it owns, or an academic researcher is let in for some information. The service is elaborate by the standards of today. In one click of the button, the information is ready for the observer. A rental service may have an online screen showing its vehicles. The price level of buying the service from an ATMS is better than the price of making a tailored system.

3.4 Architecture; the design of an ATMS

The SE level two is not intended to be detailed. Sensing and network communication are introduced. Algorithms and methods of route handling and path creation are only presented as properties.

First, a description of the network architecture. It is a provider for connections from each pole of the system to the next one, and to the server in the higher hierarchy level. Main components of an ATMS pole are explained. Principles of measurements with cameras and radars are explained. Communications technologies are addressed, and an explanation of most defining properties of new generations of cellular communication systems. How they provide the connectivity in ATMS – AV system. Below is a list of presented contents.

- The schematic structure of the network
- Layers of the network
- Road layer components
- Sensor layer. Sensing methods for the traffic. Cameras, Radars, sensor grids with observations about measurement properties
- Communication layer. Cellular communication in AV – ATMS connections.
- Gabor filtering for object identification and posture analysis

3.4.1 Main components

An ATMS has basic components located on most poles of the road. In figure 15 a lane system with poles of an ATMS next to it. The proposed way of constructing an ATMS is with cameras located about 50 m from each other. The distance is similar to distances between streetlights. Each tower is acting as a base station for the highspeed cellular communication. Vehicles passing the tower are switching from the previous base station to the next. One pole has only a few connections directly, but the ATMS has information about the traffic, animals, and objects in the surrounding environment. A network of computers updates this cloud-based resource in peer to peer fashion. The system has valid information accessible when and where it is needed.

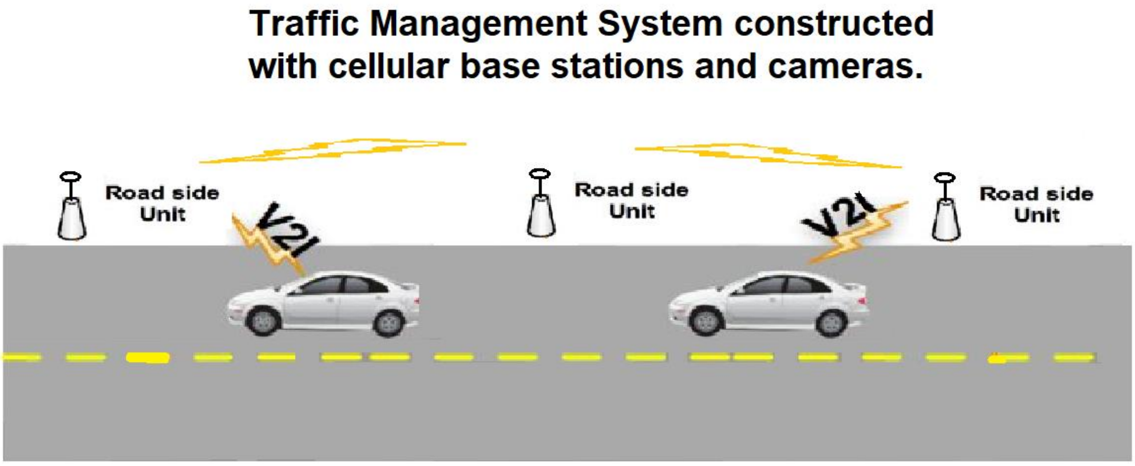


Figure 15. AVs are negotiating for an acceptable path of travel during the next timeshare. Roadside units form a cloud service by connecting to the next base station in the chain.

3.4.2 Network configuration

Networks, like the internet, and the World Wide Web, WWW, have architectures. In figure 14 are schematics of two principal modes, a client-server and, a peer-peer. When a surfer is browsing on a site on www, he is a user of a client – server-based architecture. One conceptual server provides services to many clients. It reaches leaf nodes with vertical inquiries. If the loading of the nodes is balanced, the time to reach any of the leaf nodes is approximately the same.

A peer-peer architecture is a network, where each unit is acting as a server and as a client, initiating and responding to requests of the neighboring cell. They are fast and simple solutions when a major share of the communication traffic is in the proximity of the unit.

If both features are required, fast response from every part of the system, and a major share of the communication traffic is from neighbours, a possible solution is a hybrid. Servers are acting as servers providing for many clients, and as a peer-peer node for the servers at the same level of the hierarchy, i.e. in the proximity. To a server acting on a higher level, it would be a client. For an ATMS network, a hybrid provides many advantages. In practice, tens of clients are connected to a server providing connectivity. This enables the ATMS to respond to inquiries about the present traffic, collect historical data for statistics, to supervise operability of client nodes, and it also enables maintenance from trusted systems.

One example configuration would have ten leaf nodes served by a server of the upper hierarchy level. Ten servers acting as clients for the next layer of the servers, and so on. A third layer server would have a fast link to a thousand leaf peers. The configuration is almost sparse, causing only light load on the nodes, but it would connect every vehicle in the continent with ten layers of hierarchy, and it would allow redundancy in the network. Mall function of the unit is registered, and the neighboring system takes the responsibility of the action.

Simplicity is also a provider of robustness. The software of leaf nodes and servers is kept simple.

In figure 13 is shown a schematic diagram of an example configuration. It is a hybrid network combining two modes of architecture, a Client-server, and a peer-peer.

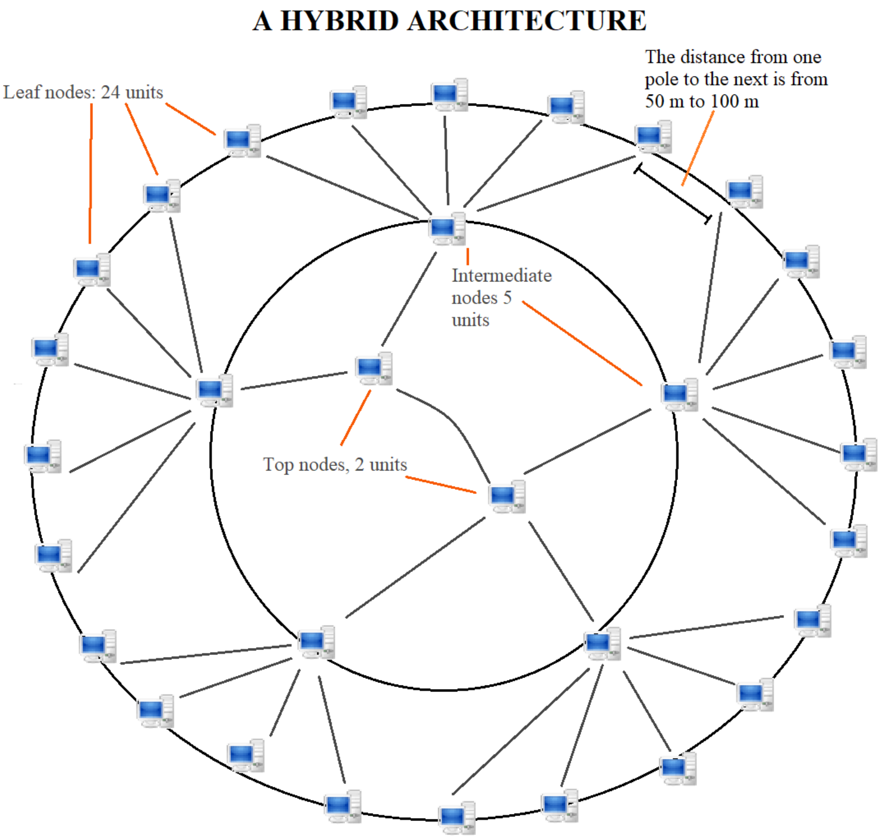


Figure 13. A simple, robust and elaborate solution for the network architecture of an ATMS would be a hybrid of peer to peer net and client-server model. Outer leaf nodes are located on the roadside poles. Locations for inner layer servers are assigned for connectivity, ease of maintenance, and the accessibility of the location. Redundancy is not a part of the diagram for improving readability.

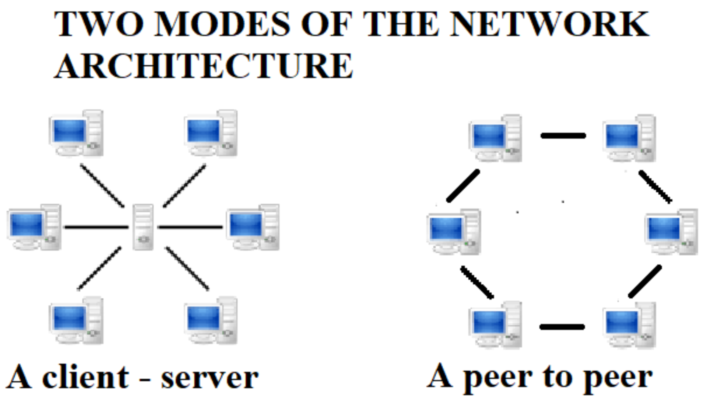


Figure 14. The example network for an ATMS has two modes. Vertical moves operate with A client-server architecture, and the traffic within a hierarchy level is part of a peer to peer configuration.

3.4.2 Layers of the network

The network might be observed as an onion with layers, and each layer has a role, differing from others.

A leaf layer is responsible for the sensor information. It collects technical data from videos, pavement grid and radar. A peer – peer connection is used for awareness of neighbouring domains to provide redundancy, calibration from node to node.

The next level is the communication layer. The one providing a link to vehicles via cellular connection. It receives IMU- and other information from vehicles and delivers guidance for vehicles to keep them on negotiated path. It is considered as a sibling for the sensor layer.

The joining of IMU- and sensor information is one of primary concerns of the system, and detailed architecture could be solved with independent unit forming state information of vehicles within the domain it is assigned to. If the source information is partial for any reason, it uses what it has for the result. The domain of state server is potentially many leaf information units for each server.

The next server layer is a road level. It is responsible for developing actual paths for vehicles. From route server it receives the road specific, or a lane specific, route information. It is aware of the part of route belonging to the domain it is serving. When the vehicle is leaving the road for another in the intersection, another road-server starts to host the vehicle.

Road servers are connected to each other in peer – peer fashion. Each intersection is a bridge or a link from one road server to another. The network architecture is analogous to the road system.

The route servers are to form and update destinations of each vehicle. They are conceptually vehicle specific. If a road server is not directly connected to road server, the communication server could use the vehicle as a provider for the route information.

Higher levels of servers are district domains, like township, county, state and federal. They are interacting with each road server within the domain.

3.4.3 Road layer components

The road has two main areas, intersections, and open road sections of the road. Within intersection areas lane changes are not accepted. In the open road section only lane changes are allowed. A Cross road is a connection from many roads to many roads. An open road has many regions allowed for lane changes. Highway exits are considered as lane changes.

The structure of the road map is much like a neural network. A server layer or a virtual server might be dedicated to combine the road system. Each intersection is a cell in a neural network with weights and route server is capable to find the route from A to B with it.

3.4.4 Path selection, two methods

The refinement of the path selection has a lot to do with customer satisfaction. It would be possible to allocate a tube in the space of lane distance from the border of the domain and time. It would secure one share of the traffic from colliding with each other. Automated vehicles would be traveling on pre-ordered paths. Unknown traffickers and objects would cause vehicles to change the path and it would make others react by driving outside of the plan. Such a simple version could use speed limits with adjustments according to weather and vehicle type. It would not be optimal with the use of resources. The system would not know the limits of performing very well. Emergencies caused by unexpected interventions would not be getting optimal responses from such a system. When there is a need for a refined path to avoid an obstacle on the lane, like a log from a truck, it would be left for the vehicle to survive.

An advanced version of the path selection would allocate the road with the vehicle size instead of lane width and have a valid simulator for forecasting reactions of the vehicle in the situation. Each vehicle is having essential inertia values and torques on the wheels. The IMU-chip produces data about accelerations, positions, and speeds of the perimeters of the chassis, and Centre Of Gravity, abbr. COG, of the vehicle. Information is readable to the ATMS unit, and it can guide vehicles with new shares of the lane space path within limitations of the physics. And it can guide other traffickers to provide adequate space for every vehicle. The advanced system would improve the safety, performance and comfort levels of the traffickers. It would allow them to do with their businesses when they prefer.

3.4.5 Sensing methods of sensor layer

Detecting, positioning and identifying vehicles, pedestrians and animals are requirements for systems providing detailed driving plans. For the purpose, different sensing methods are required. The reason for some objects being out of scope for some methods is in the difference compared to vehicles. The size, the material and how it moves are different. The signal is considered out of scale, or the sensor responds mainly to the properties of one of the materials. Some sensors react to the weight of the vehicle, and lighter travelers are not responded to.

The study is emphasizing videos, radars, and grids of sensors located in the paving material. Lidars, ultrasound, and others are possible, but for this paper, they are considered either expensive, unreliable or otherwise problematic. The (FHWA_detect 2019) is a detailed list of sensors currently used in traffic automation solutions.

3.4.6 The camera system of an ATMS

One motivation for videos in an ATMS is the identification of those objects who are not connected with cellular link to it. Units without readable values from an IMU are identified and trajectories of them are forecasted, if the result of it is considered credible for the situation. They aren't always sensed with road sensors or radars. And if they are, results are not very informative for the classifying purpose. Visual information from cameras is used for it. With infrared sensor, abbr. IR, identifying can be improved. The difference from animals to other objects is made clearer with the data about IR reflections.

The distance information can be generated from two 2D images of the same area, if they are taken from different locations. This technique has been around for some time, though it is reaching new heights today because of the developments of technologies enabling 3D imaging and analysis of the material in real-time.

In figure 16 is shown, how four 90degree view angles might be positioned. Cameras on adjacent poles are in the next figure. Highspeed link between cameras enables to generate the distance and the speed information from two cameras covering the same area.

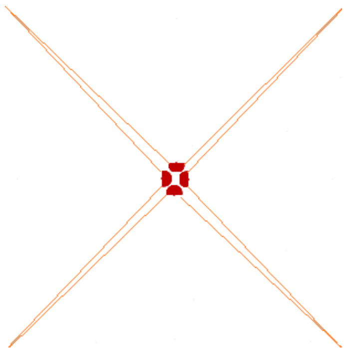


Figure 16. One camera pole has four cameras for observing traffic, animals and other changes in the environment.

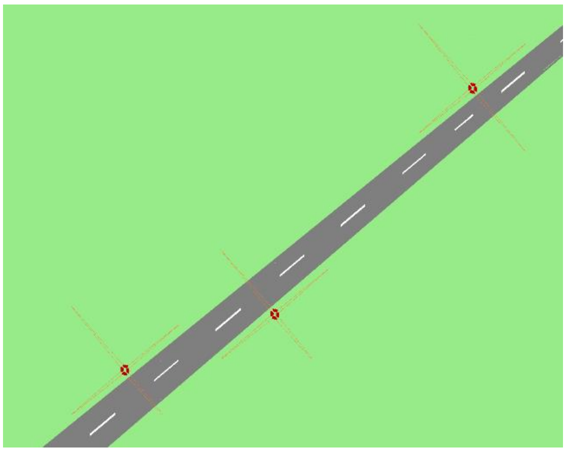


Figure 17. A setup for view angles of the cameras.

3.4.7 3D information from the video material

information from the video material is drawn in the diagram in figure 18. Information can be made more reachable for computation in different ways after the object is extracted from the rest of the picture. For example, few dots are selected to represent the outline of the entity in both pictures. So, calculations are simplified.

Limiting factors are the resolution of cameras, view angle of objects and the distance between two cameras. If they are equipped with different resolutions, view angles or the distance from cameras to the measured object is different, calculation processes needs to be adjusted. The information is still available, but differently. Very wide view angle is a complication, because the pose of measurement points is different, and analysis is not easily generally valid.

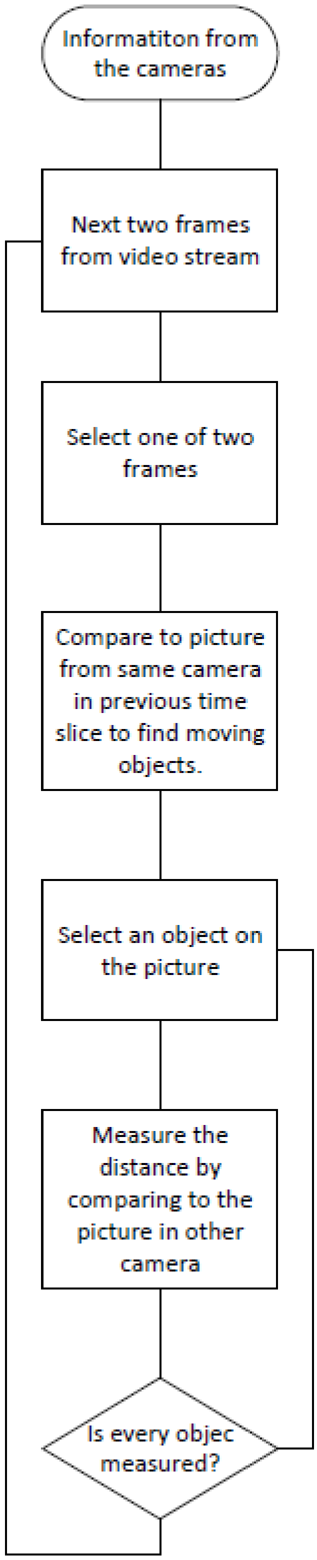
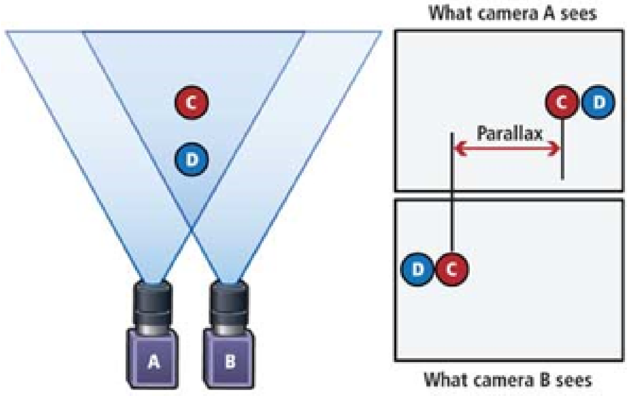


Figure 18. Processing associated video materials with photo imaging.

Simplified set up for distance calculation is shown in figures 19 and 20. When cameras are pointing to same direction and they are at similar distance from the measured piece, can evaluation proceed with equations 1 – 3. (Pennwell 2017)

Figure 19. 3-D information is created like in the setup of the left side of the picture. Smaller difference in the horizontal location (parallax) of the C compared to D between two sensors indicates the distance from the cameras to C is greater (Pennwell 2017, p. 1).



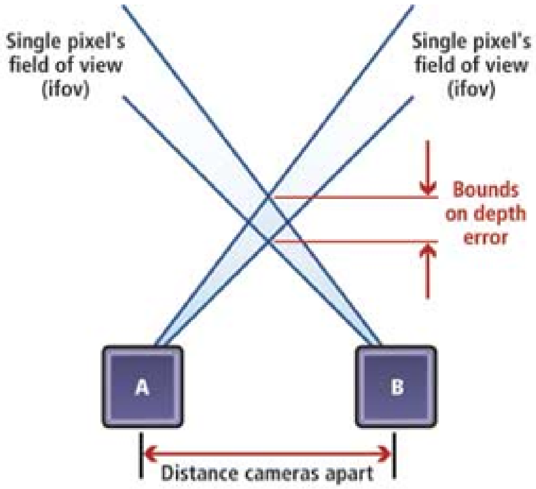


Figure 20. Schematic of relation between distance of cameras and distance of the object (single pixel's field of view) and how cameras define the resolution of the depth measurement. The horizontal resolution of the pictures is definitive (Pennwell 2017, p. 1)

The maximum error of distance information can be quantified as:

$$Max\ err = \frac{dist_{object} \cdot \frac{1}{2} \cdot x_{pixel}}{\frac{1}{2} \cdot dist_{cam\ apart}} \tag{1}$$

where $dist_{obj}$ is the distance of the object from the cameras, x_{pixel} is the horizontal dimension of one dot, and $dist_{cam\ apart}$ is the distance between cameras.

An example of reachable accuracy with 8k video:

- The distance of the object from the cameras is 50 meters.
- One pixel covers 0.01 m wide area when the horizontal view of the camera is with a 90º view angle 50 meters.
- The maximum error can be quantified as:

$$Max\ err = \frac{50\ m \cdot 0{,}005\ m}{10\ m} = 0.025\ m \quad (2)$$

The value can be improved with the change of the view angle. The Size of pixel x_{pixel} could provide five times better distance information if the view angle is narrowed to the 14 meters at a distance of 50 m. It would require cameras on the pole to view on the area starting from the next pole.

One example calculation is provided about the estimation of the value of reachable accuracy in the distance measurement. The example is based on the requirement of 2% accuracy for the speed information. If it is evaluated every 1/30 s. and 2,5 cm resolution in the video is used, we can use (3) to evaluate the lowest speed with 2% accuracy.

$$distance = time\ \cdot\ speed$$

$$accuracy = \frac{resolution}{distance}$$

$$distance = \frac{resolution}{accuracy} => \ speed = \frac{resolution}{time\ \cdot accuracy} \quad (3)$$

$$speed = \frac{0{,}025\ m}{\frac{1}{30}s\ \cdot\ 0{,}02} = \frac{5}{4} \cdot 30 \frac{m}{s} = 37{,}5\ m/s$$

3.4.8 The radar system of an ATMS

Radar is an alternative way to measure the locations of the vehicle. With three receiving antennas, an FMCW radar can measure distances, positions, and speeds. It is also aware of stationary objects. A radar used in the paper (Liu & al 2018) is a 77 GHz Frequency modulated continuous wave radar abbr. FMCW. (Iovescu, Rao 2017)

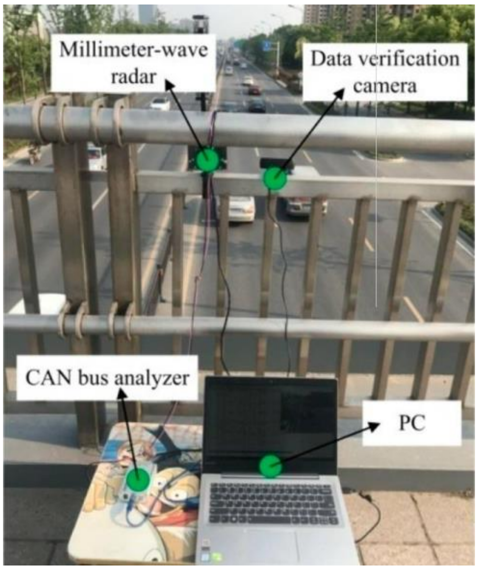
Measurement of the FMCW radar is based on the chirp-signal in figure 24a. It is continuously and linearly changing the frequency from the base level to higher frequency until it reaches the roof of set bandwidth. A new chirp starts from there. The Iovescu & Rao paper is using a 77 GHz – 88 GHz signal.

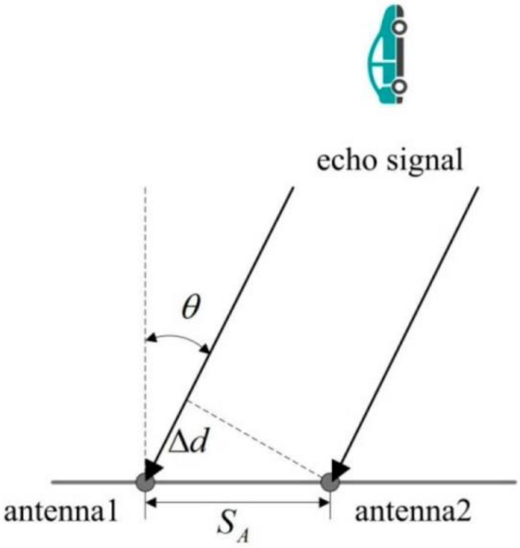
The radar sends continuous chirps and receives echoes from the environment. The received signal is compared to the signal presently sent with the time difference. Amplitudes of signals are scaled, and results are summed to one continuous waveform. It is analysed with a Discrete Fourier Transformation method. It produces a list of component waves with the frequency and the phase information. Components are reflections of different objects. The frequency of the component is caused by the time difference of presently sent and received signals. The chirp has changed to different frequency during that time. The combined signal has a frequency of the difference between the two frequencies. It gives the distance result for the object reflecting the wave.

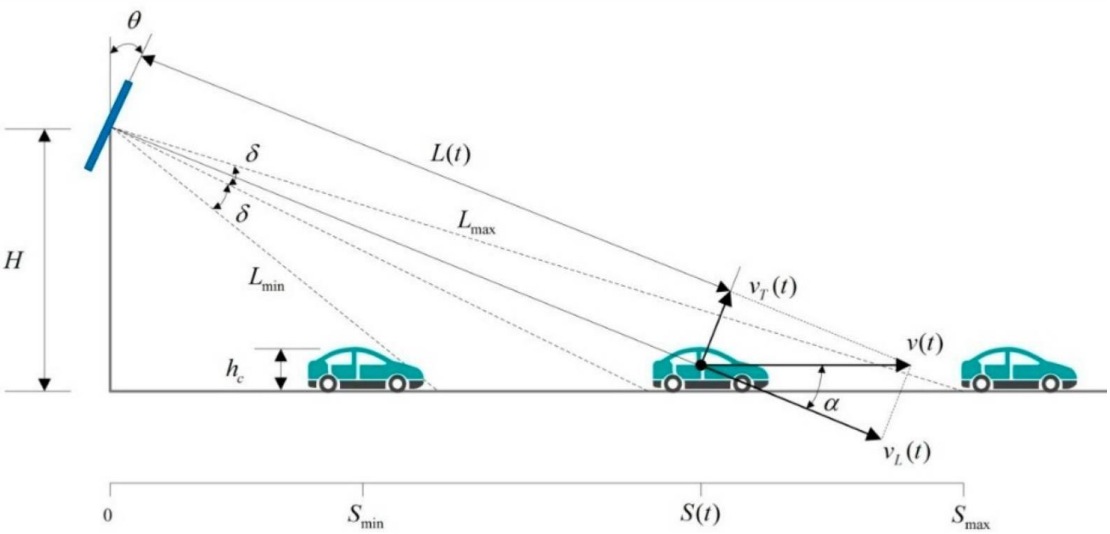
The speed is measured with the phase difference of sent and received signals. The movement of the object during the reflection of the signal causes the phase angle to increase or decrease, depending on the differential increase or decrease of the distance at the time of reflection. The principle is the same as in the doppler effect. A Plain doppler radar is not used, because it is not aware of stationary objects.

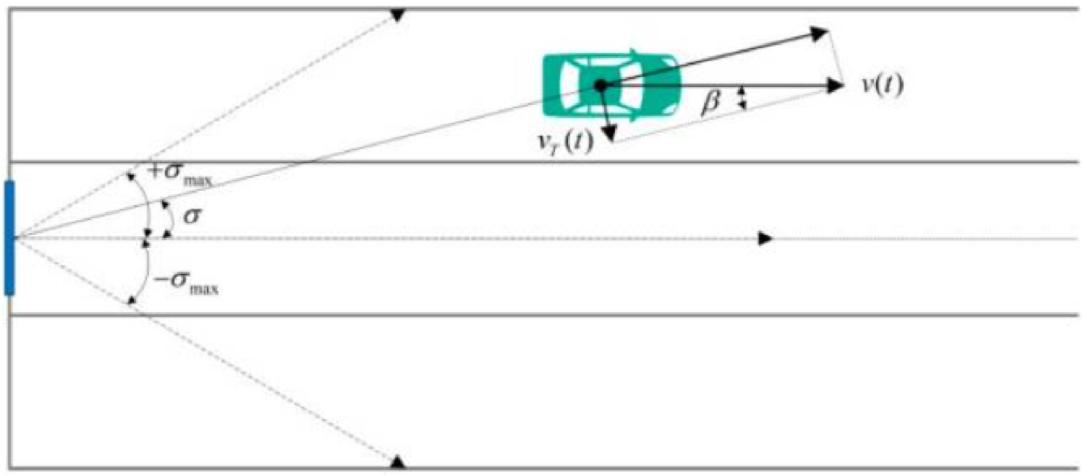
Positioning angles from radar to vehicle are also needed. Figures 22a and 22b shows, how two receiving antennas are used to measure one of the angles. The system needs both vertical and horizontal angles. Three receiving antennas are used in a triangular formation to provide for them.

A phased array antenna in figure 24b is an example of how linear properties of waves can be used to create a wavefront. It enables the analysis of the yaw angle. When the angle of the wavefront is changed, the received signal also changes. By comparing returned chirps with each other, the alignment of panels of the vehicle with the wavefront can be deduced.

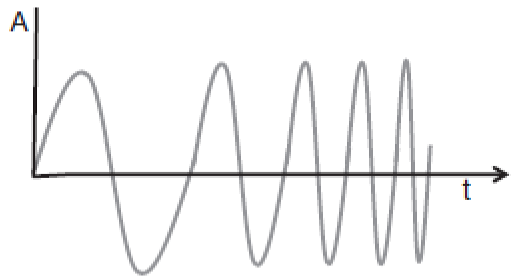








Figures 21, 22, 23a and 23b. The picture shows the setup for Liu & al, diagrams explain the principle used for locating the vehicle. (Liu & al 2018)



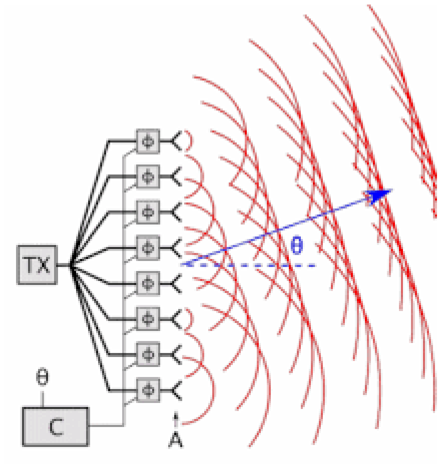


Figure 24a. A chirp signal has an increasing frequency until it returns to the base level. (Iovescu, Rao, 2017)

Figure 24b. A phased array antenna type allows the system to analyze objects also with angles of main surfaces. The chirp reflected has a higher amplitude, when the wavefront is in the same angle with the main panel.(WikipediaPhA 2019)

3.4.9 Sensor grid in the road structure

Radar and light-based information systems provide some redundancy. Often, a grid of electromagnetic sensors would provide an additional method to measure properties of traffickers. Also, acoustic waves are used in systems of the day. Both systems function with vehicles, but with animals, they are not similar. (FHWA_detect 2019)

3.4.10 Speed and acceleration information

Speed and acceleration information is usually acquired from the vehicle to an ATMS with a cellular connection. The system needs have an ability to measure those values by itself with the information from radars, road sensors, and cameras. Values received from an AV are compared to a material from an ATMS to secure the validity of both systems.

3.4.11 Acceleration information from videos

An acceleration measurement is derivative of speed. It is computationally expensive process to use high resolution cameras to reach reliable measure of the speed change. For an example, if 30 m/s speed is assumed, and if the 1/10 s resolution in time is preferred, the vehicle travels 3 meters. With acceleration of 1 m/s^2 the speed would change 0.1 m/s. The change of the travelled distance would be from 3 m to 3.005 m. It would require a resolution of 1 cm for the distance information to get usable acceleration information with the example setup. Mass produced cameras are not very precise for the acceleration information. Technologies are improving and enabling acceleration measurements from the video material with usable accuracy, but today an IMU-chip of the vehicle, radar and sensor grids are better choices.

3.4.12 Postures of the vehicle, Gabor filters, and IMU

An ATMS should know postures of the vehicle, i.e. pitch, roll, and yaw angles. They allow the system to verify the path plan for validity. If an exceptional situation causes a vehicle to be distracted from the projected path, an ATMS must know what to expect. It changes path plans of the distracted vehicle and plans of other vehicles also if required.

Methods for the information are the Inertial Monitoring Unit, abbr. IMU, of the vehicle, and information from the camera systems of an ATMS. Also, information from the radar can be used to verify others. If one of the systems is out of service, measurements are still providing some information of the pose.

The information from cameras needs some processing and Gabor filtering might be used. It is a method to read the weight of a pre-set angle in the picture. If vehicles are generally driving in same direction and are similar sized, a filter bank of five filters could give a confirmation about the pose of the vehicle and provide for the identification of it.

Individual filters are tuned with different directions and frequency settings to produce output from the same source material. In figure 25a, is a demonstration of a bank of filters and in figure 25b is a result with the filter bank, when a vehicle is observed.

In the paper Complexity-Aware Gabor Filter Bank Architecture Using Principal Component Analysis (Lee & al 2017) is a presentation of the system to reduce the computing load of filtering when a bank of filters is used.

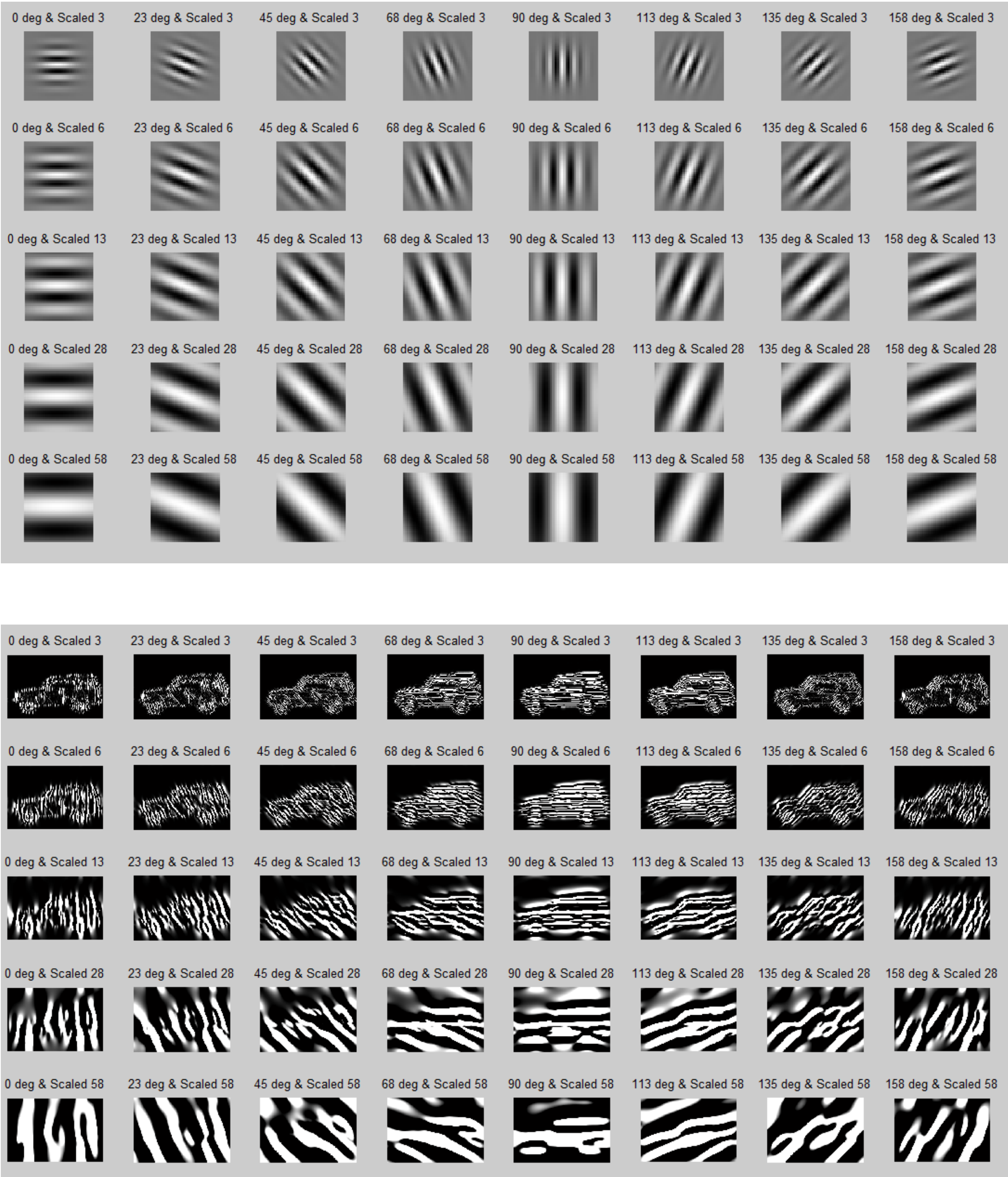


Figure 25a and 25b. A demonstration of Gabor filtering for vehicle identification and pose analysis. (StackOverFlow 2019)

3.4.13 Technologies for ATMS – ATMS, and ATMS – AV communications

ATMS has a central role in communications. Even if some vehicle to vehicle, i.e. V2V, communication protocols have been proposed, it will be improved robustness and simplicity of systems, if AVs are connected to an ATMS only, instead of thousands of other individual vehicles. In the areas without road guidance, i.e. silent roads where an AV is in independent mode, would it be an advantageous feature. A vehicle is safer when it is aware of the actions of nearby vehicles in advance.

The system requires valid communication capabilities. It is made possible by the arrival of 5 G and 6 G mobile technologies. They provide today data transfer speeds of 1 – 2 gigabytes/s or 10 – 20 gigabits/s with the use of 300 GHz frequencies. About one-millimeter wavelength. The Switching time from station to station is in the 5G system few milliseconds. It enables an ATMS to have a cellular base-station on each pole and AVs can interact directly with the nearest pole. (CNET 2019)

Electromagnetic milli meter waves require direct open line from the antenna to antenna, or from vehicle to base station. Also, cameras, radars and sensors require a set up with poles every 50 to 100 meters. In practice, a pole will have only a few vehicles connected to the base station of it at a time. This is to make the situation of eight lanes filled with traffic simplified by assigning every lane with dedicated ATMS units. They are configured to negotiate about incoming vehicles with four stations: left, right, front and rear. Figure 26 shows a demonstration of today's most complex city trafficking, an urban highway configuration in china.

ATMS – ATMS communication is possible with other technologies also, like optical fibre. Leaf level network responsible for sensor information is potentially transporting live video material, grid information from the pavement and radar signal from a pole to another. It would be preferable to use adequate number of fibres for the traffic.

Figure 26. Urban trafficking in China. There would be like a hundred ATMS stations for a thousand AVs. (Tripsavvy, 2019)

3.4.14 Robustness by redundancy

A trafficking solution is generally required with high reliability. To provide continuity in the trafficking, an ATMS is made redundant in many ways. First, vehicles have originally the capacity to travel in autonomous mode. When an ATMS is present, the mode is switched to the ATMS. The next level of redundancy is gained by allocating an individual ATMS unit on every camera pole and assigning dedicated poles for every lane. Each ATMS unit needs to be capable to serve the traffic of the neighboring poles from at least two directions. So, if one unit is out of service, vehicles on the domain of it are connected to the neighbour. It keeps the system reliable, simple and extendable. Any number of lanes is serviceable.

3.4.15 Vibrating poles, methods for accuracy

Any structure is liable to vibrations. Two paths for the accuracy of the measurement are mechanical stability and reducing errors caused by the vibrating environment computationally. For example, modes of vibrations can be taken into the stabilizer system, which might be a hybrid solution involving dynamic, static and computational modifications to the supports and measurement software.

3.4.16 Standardization

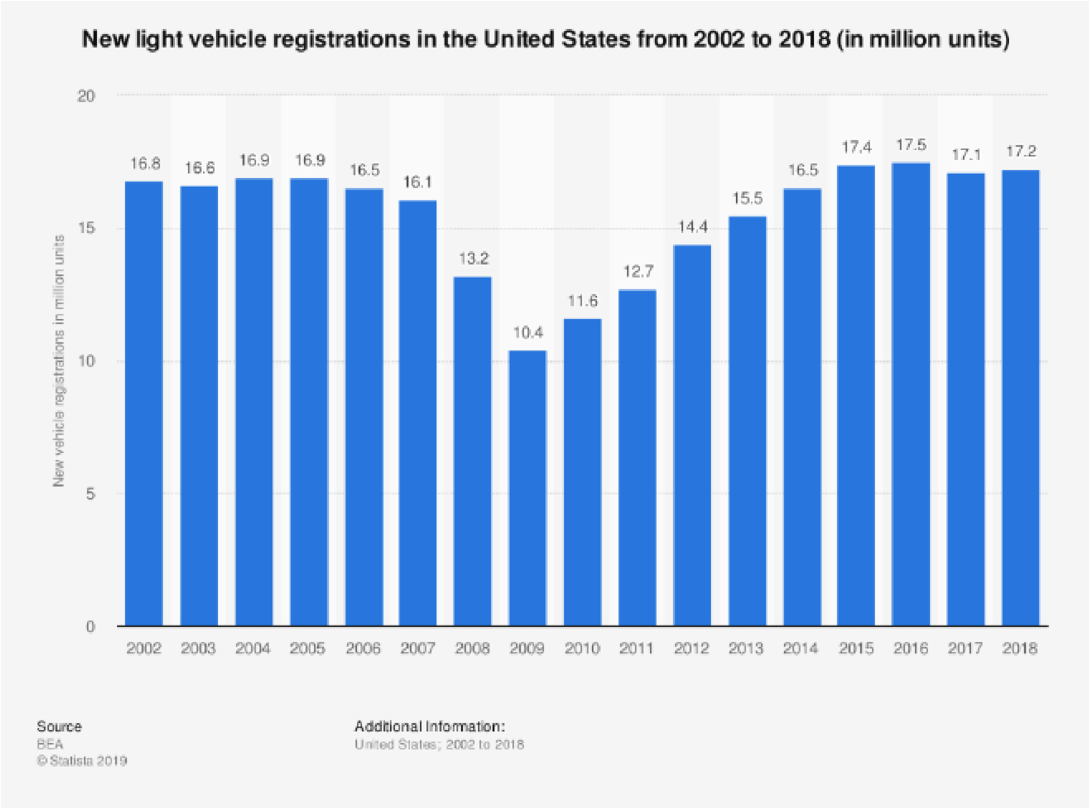
It is possible to define an ATMS only if the interface to an AV is detailed. In the U.S., the EU and Japan national standardization organizations have started the work to develop standardization on Intelligent Transport Systems, ITS. Existing ITS standards need to be upgraded to provide an environment for developing combined ATMS – AV systems in a multivendor setup. (US_DOT 2019; JSAE 2019; CEN 2019)

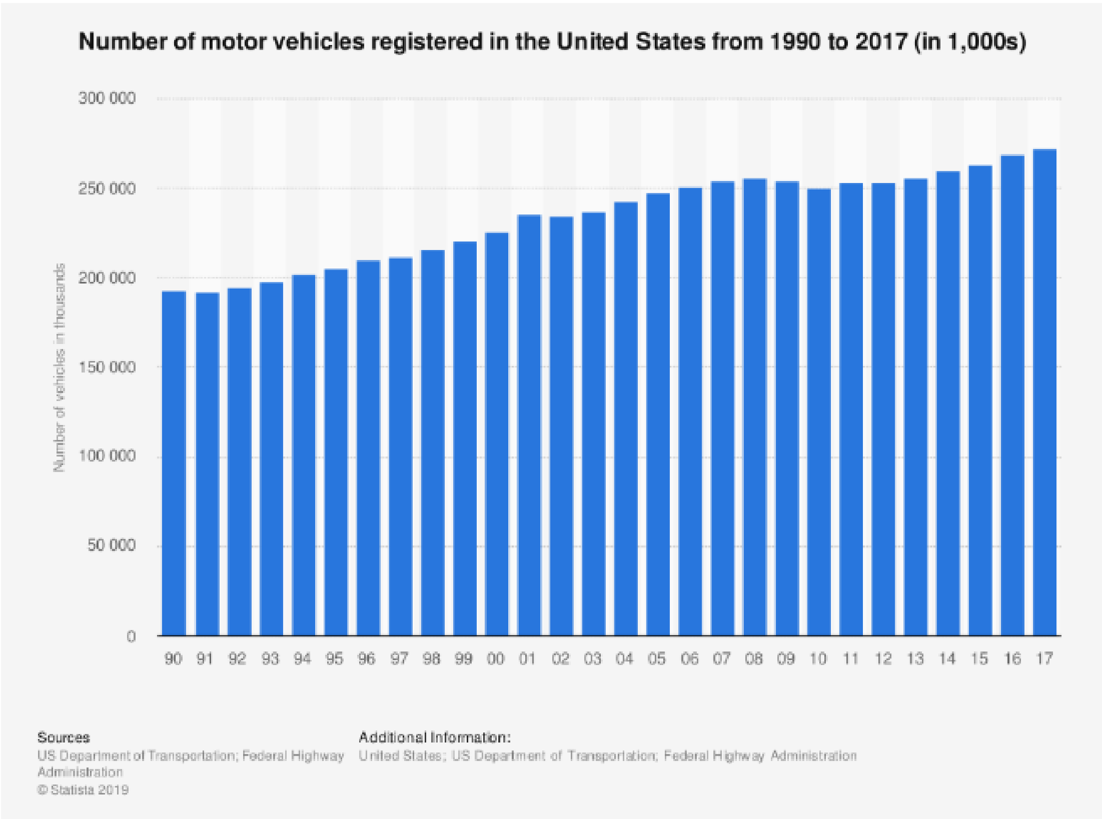
3.5 Implementation issues, price of an ATMS

The price level of ATMS units is comparable to the price level of the automation of the AV. The number of ATMS poles is similar with or less than the number of vehicles on average. The number of vehicle miles driven on the road system varies significantly between different areas. Generally, implementation of an ATMS is profitable for traffickers, i.e. payers of the trafficking.

estimated number of poles is 32 / mile. With 4,09 million miles, it generates 130 million units. Vehicle count is today about 272 million. About twice the number of poles **(**Elswick 2016; Statista_VEH 2019)

The vehicle base is renewed currently in about twenty years. (Statista_NVEH 2019; Statista_VEH 2019). If the equilibrium with the appearance of AVs holds, ATMSs are going to evolve during the next 25 years. Figures 27a and 27b shows statistics implying the renewal rate of the vehicle base. The rate is strongly dependent on the economic developments, seen in the figures for 2008. When forecasting the renewal rate in the future, some caution should be exercised about the reliability of the numbers.





Figures 27a and 27b. The rate of change in the vehicle base is deduced from statistics in the picture. (Statista_NVEF 2019; Statista_VEH 2019)

4 DISCUSSION ON EFFECTS OF AN ATMS HAVE ON PROPERTIES OF TRAFFICKING

Terrain based trafficking is changing. An ATMS technology enables road traffic to be as economical as track traffic. It has flexibility, by enabling a door to door service with a vehicle for the trip. The rented vehicle can be one of many variations a hotel, an office, or a playroom for kids.

4.1 Concepts of traffic brought by AV – ATMS technologies

ATMS is part of future trafficking. Below is a follow up on solutions made possible by improved precision on the drive of the vehicle.

4.1.1 Trains formed by individual vehicles.

The nature of trafficking is changing with driverless vehicles. With an ATMS connection, they can utilize significantly more information compared to a conventional human driver. Hiring a trip from AV rental company is a door to door service and may include Highway traffic with higher speeds compared to today's trafficking. Vehicles are likely to be designed and manufactured to function as an independent unit able to form highway trains in the guidance of an ATMS. It saves resources by increasing throughput of the highway system, and energy by reducing turbulences of the surrounding air.

Travelers are free to do with businesses, while vehicle negotiates with an ATMS about details of travel. The driving on the train is negotiable. Each vehicle is free to choose between private trafficking and membership in a chain of vehicles. The mode can be switched at any time of the travel they choose. Speeds are expected to be higher, due to improved safety levels gained by an ATMS connection, and improved energy efficiency of the vehicles, and vehicle trains.

4.1.2 An active suspension system

The suspension system receives detailed information about the road from an ATMS. It can lift or lower the wheel height with high levels of speed and accuracy. The vertical load on chassis is kept stable within limits of the elevations of the road and travelers experience the ride smoother. The system allows tires to be significantly hard. Reactions of the vehicle are faster, the drive is more energy-efficient, and higher velocities are possible.

4.1.3 Electrification of vehicles from the surface of the terrain

The Electrification of trafficking is a trend. It allows the energy to originate freely from different sources. An ATMS enables technologies for delivering the current to vehicles during the drive. It makes vehicles lighter and more economical. Rare metals are not needed as much, and accelerations are faster with the same energy consumption. The system requires an ATMS before it is operational.

The economical transfer of electricity with power levels needed in trafficking requires a conductive contact area between the road and the vehicle. Tires might be used, when they are manufactured with additives providing conduction from surface to threading of metal or some other material. Even with small resistance from the power source to usage point, the potential needs to be high, it would be a problem for animals and other random agents. The power is switched on only if the tire of the vehicle is on the electrified area of the lane. The task of an ATMS is to do the switching of power.

The width and length of the switchable zone are one of the design issues. The length of the zone with electrical potential should be from the size of the contact area of a tire to about one yard. It would keep only one vehicle connected to the circuit at the time and enable valid measurements of the power usage of an individual vehicle, even in a train formation. Two elements should be on simultaneously during the on-off sequence to provide a continuous flow of current.

The width of the element is a function of the width of the road and the variation of widths of vehicles. It is not considered here.

To enable driving in the environments with a significant number of pedestrians, like in towns and metropoles, vehicles are equipped with either batteries or some fuel-based generation unit for power.

4.1.3. Vehicles in the low-pressure tubes

Ultrahigh speeds of the high-volume trafficking would gain from decreased air pressure. If the comparison is made with levitating trains, speed levels are reaching speeds of air traffic. An example of tube traffic is a point to point tube with serial airlocks. A train of vehicles made with standardized cross-sections driving through automated doors. The airlock has a vacuum tank connected to the air pressure regulator, i.e. airlock. After the door is closed, air pressure drops in a second by opening the valve to the tank.

The door to the new air pressure level is opened. The speed in an airlock is normal terrain speed and the traveling speed of the low-pressure tube is accelerated or decelerated after or before an airlock door, depending on the direction of the travel.

The solution would enable a heavy cargo to travel ten times faster compared to traditional truck traffic, and travelers to enjoy services of roomy vehicles, instead of an airplane seat.

Tube traffic has the potential to change some features in communities significantly. It enables warehouses serving the whole continent within hours of arrived requests. The net value of passive equity tied to products waiting for the buyer would be reduced from the current situation. Spare parts and groceries would be served from producer to client without extra interventions.

The price of the concrete tube and equipment needed for transforming it to the vacuum channel for electrically powered vehicles driven by robots should not be excessive compared to standard highways. Coast to coast highway solution would already be 3000 miles and ten billion dollars. Exact figures might be sought for. They depend strongly on the need for tunnels bridges. Generally, the route makes a difference, because tight turns and rapid elevations are not desired in a highspeed environment.

An intercontinental tube would provide the whole world market with response times satisfying even busiest clients. Capabilities of the underwater construction are improving with autonomous technologies, and it would make tubes from continent to continent possible. The price level is a function of the motivation of builders. It is a giant leap to start a business with the abilities needed for the construction.

A Connection from continent to continent rises many technical details. It must be made a safe and recoverable form of transportation. One broken magnet or axle should not cause a disaster for thousands of vehicles in the tube. Methods of recovery and rescue must be defined and priced early in the process.

Energy would also be an area of interest. Power for tubes with a length of thousands of miles is an issue with many plausible solutions:

- Superconductor technology would allow efficient power delivery for long distances
- Underwater powerplants are technically a possible solution
- The route is set with isles, like Greenland and Island

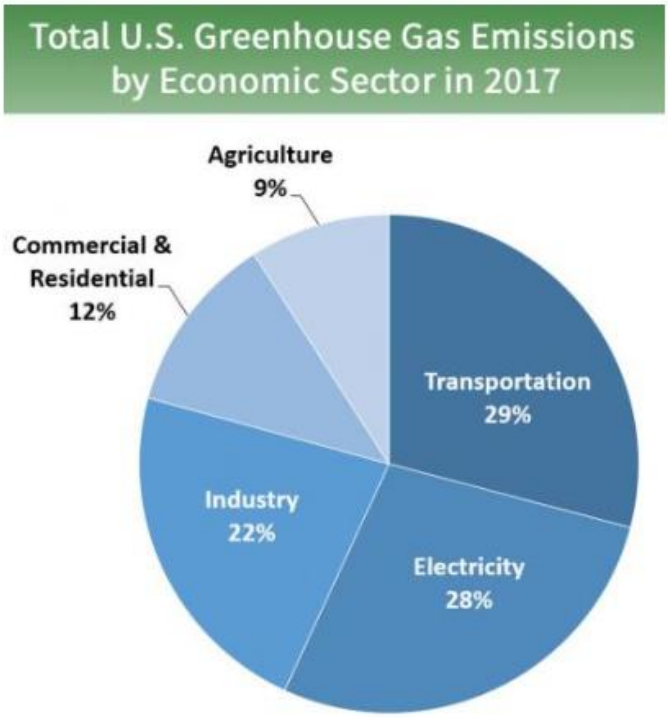
The subject provides basis for a lot of research and business. Use of magnetic levitation in heavy freight traffic in a form of bearings or on weight carrying surfaces would provide for ultrahigh speeds. Combining it to door to door services provides a most versatile solution for mail-order business.

4.2 CO_2 load caused by traffic

Currently, about 70% of the oil used in the U.S. is due to road trafficking (EIA 2019). About 1.872×10^{12} Kg of CO^2 is produced by traffic 2017 (US_EPA 2019). The world figure is estimated to 36.17×10^{12} kg in 2015 (US_EPA 2019). U.S. traffic emissions are about 5.1% of greenhouse gas emissions in the world.

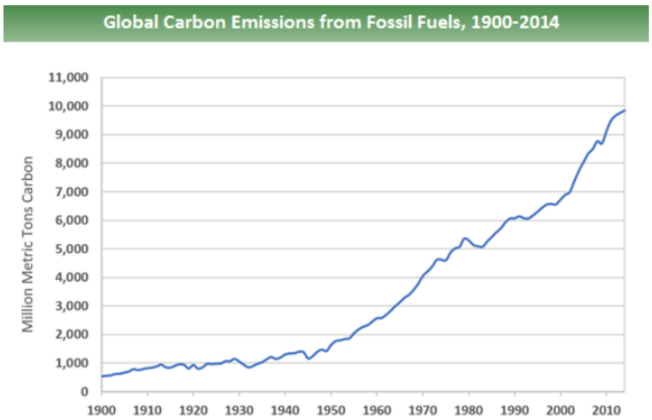
In figure, 28b has estimated carbon emissions of fossil fuels. If the figure is multiplied with $(12 + 2 \times 16) / 12 = 3.66$, the result would be 36×10^{12} Kg as in (US_EPA 2019). Figure 28a shows the role of transportation in the greenhouse effect. 29% is similar to the share of transportation from the total energy consumption in the U.S., figure 31. When electrification reaches carbon-free state and trafficking is part of it, carbon emissions would be reduced by 60%.

The increase of a CO_2 concentration is about 2.2 ppm / 405 ppm in a year, approximately 0.5%. The preindustrial level is measured from air bubbles in the ice of glaciers, and it is estimated to 260 – 280 ppm figure 29. At the same time, the average temperature of the surface air rose about 0,8 degrees in the Celsius scale, figure 30. The heating power of the greenhouse effect is estimated at 3 watts per square meter, and it is linear to the greenhouse gas concentrations in present concentration levels. (Lindsey 2019).



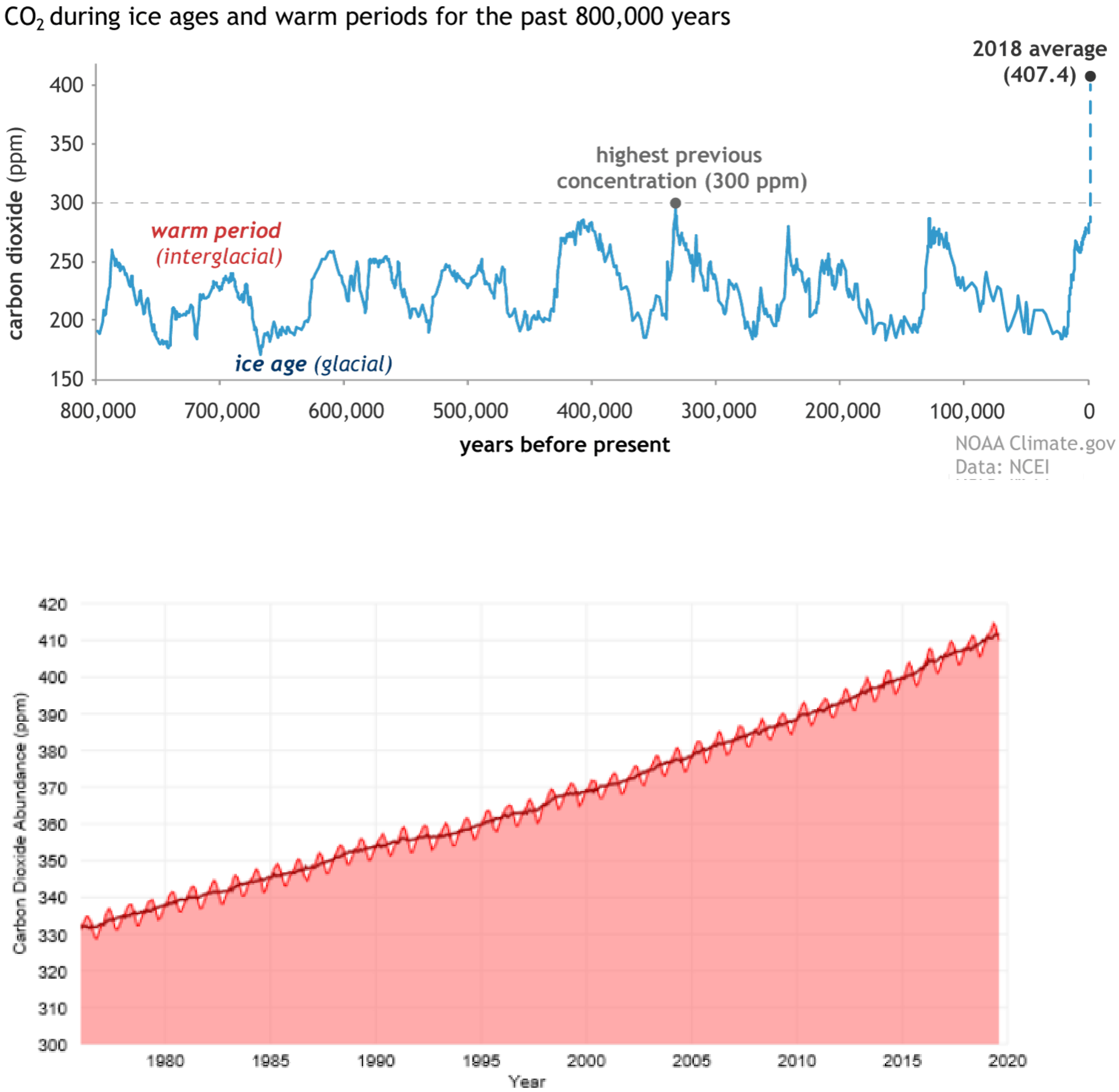
Total Emissions in 2017 = 6,457 Million Metric Tons of CO_2 equivalent. Percentages may not add up to 100% due to independent rounding.

Trends in Global Emissions



Source: Boden, T.A., Marland, G., and Andres, R.J. (2017). Global, Regional, and National Fossil-Fuel CO2Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2017.

Figures 28a, 28b. Global greenhouse gas emissions and global Carbon emissions. (US_EPA, 2019)



Figures 29a and 29b. Carbon dioxide concentration in atmosphere. (Lindsey 2019)

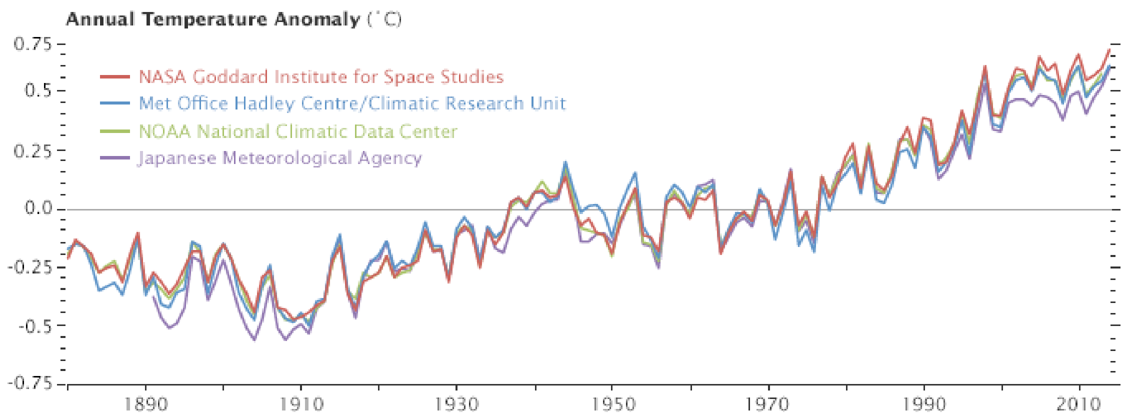


Figure 30. The average temperature on earth has risen 0.8 degrees Celsius since 1880. (NASA 2019)

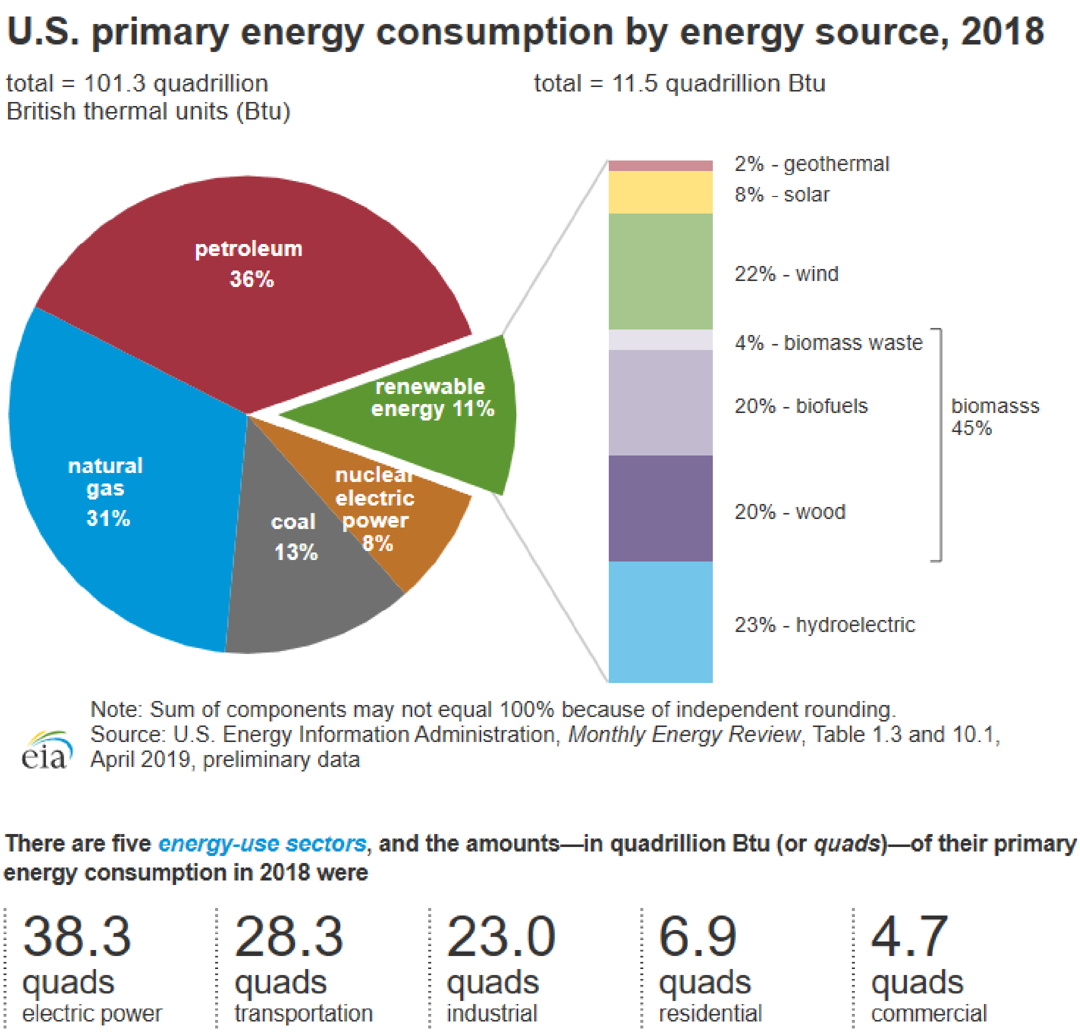


Figure 31. Transportation is 28% of total energy consumption in the U.S. 2018. (EIA_ETOT 2019)

The electrification of the vehicles is a significant factor for stabilizing the carbon content in the atmosphere. New technologies enable lighter, faster and simpler vehicles with electric motors and light batteries for trafficking in metropolitan areas.

The average power consumption of road traffic in the U.S. is about 1 terawatt. (EIA, 2019). The figure is about the same as the electricity-producing capacity there. It would imply 300 x 3 GW power plants. A price tag of about 3 Trillion dollars. It is about a one-year trafficking price in the area. The electrification of roads or at least vehicles would seem to be plausible during the next 30 years.

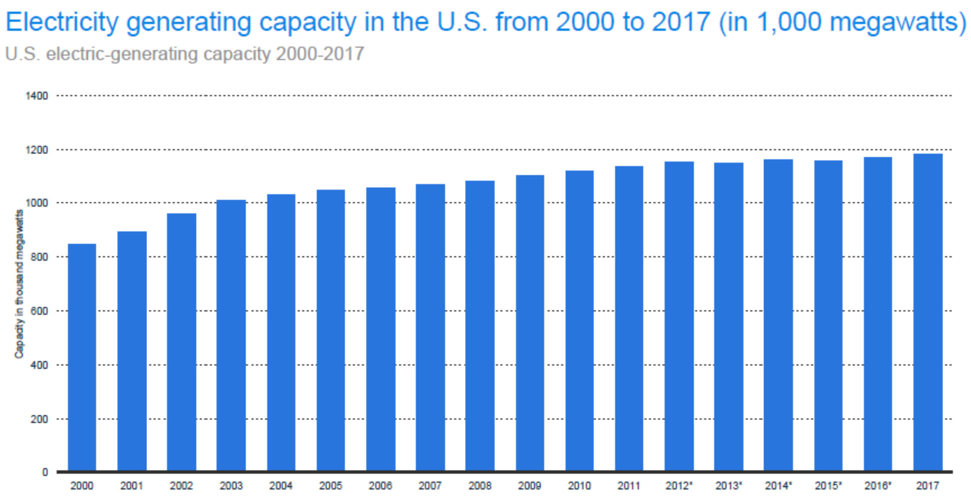


Figure 32. Energy production capacity in the U.S. (Statista_EP 2019)

4.3 The pricing of the road

Generally, people prefer to allocate payments to those who cause them. They are not always considering the use of the road as the use of an expensive resource. It appears to be in a similar price group as the energy of trafficking, or vehicles. In the U.S. fuel taxes are collected for the upkeep of the highway system. It is not covering construction projects. Trafficking fees should be capable to provide funds to cover manufacturing and maintenance road. If monopolistic development occurs, some form of regulation is needed. The government could provide subsidies for traffickers receiving competitive pricing from the road company. It would increase the revenue of the road company, and pricing policy would be regulated.

The naked price of the road is evaluated with DFC and WACC methods. The investor planning to invest in the form of the road, or planning to buy an existing road, has the initial payment to be made. He evaluates every cash flow for the lifetime of the investment and discounts them with the expected cost of cash. It is and weighted average of the interest rate of available debt and price of the equity. The company is to provide owners some form of compensation for their investment, for example, the dividend-paying system. The weight in computation is the leverage in the funds of investment. If half of the money is coming from lenders and the other half is from the equity of the company, the Weight for both would be 0,5. Cash flows should stand for every vehicle mile driven on the investment, and the price of miles driven with different vehicles is varying. The price is also changed by traffic load during the time of trip.

The valuation process gives the investor some price level needed for the investment to be profitable. Risks are for example in the changing debt rates. Also, the minimum cash flow may not be reachable due to other reasons. The expected volume of the traffic is not reached, or the price level required is not reached, because of the competition or fewer clients profiting from the service.

The competition would be in the form of new roads or new modes of trafficking in the area. Diminishing the client base could be due to deindustrialization in the area. The demise of Detroit is one example of it. The population of the town was 1,030 million in 1990. Year 2017 it is 673 000. From 2009 to 2010 it dropped to about 110 000 in one year. (United States Bureau of the Census 2019). If one-third of the client base is not present, or they are not traveling as much as expected, the road company would be in trouble. The investment is to last tens of years. The topology of the map, how conurbations are located, is a dynamic feature. Roads, and traffic on them are adapting to changes in communities continuously.

Another set of risks, debt rates is significant. Rates tend to proceed in long trends, figure 33 (Dalio 2019).

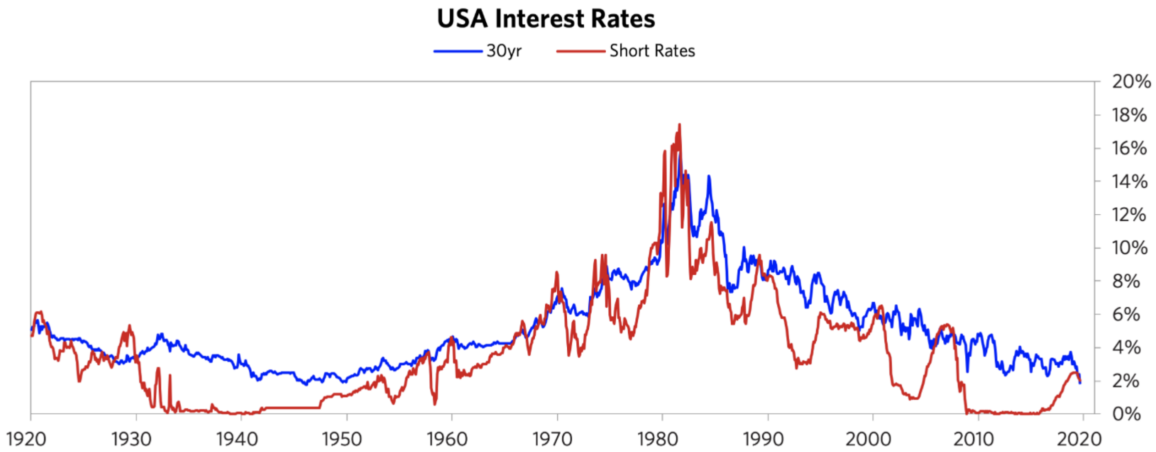


Figure 33. Interest rate from 1920 until today. (Dalio 2019)

Future expenses are forecasted. Future incomes are determined by the market. If the road system has two routes from A to B, the price would settle about to the price of the next best route. For example, one road from A to B has the length and expenses of 100 units and the other with the length and expenses of 120 units. The faster would win, even with a price tag of 120.

The pricing of the new road should be free. If the company has met the needs of travelers, it would make a profit. If not, investors would be strained from the value of their investment, and the company would be in a bankruptcy situation.

Monopoly tendencies should be regulated. If one company owns every highway from a town, it would essentially be in the position to tax citizens for their freedom to travel. The solution might be to subsidize fare fees below set values and regulate ownership of adjacent roads. They would have to be owned by different companies, and those companies should be filtered from cartel connections.

The time from investment to healthy returns is in the road business longer due to the nature of business. Changes are in the business environment. The production unit, i.e. roads, is a reasonably stable factor. Maintenance needs are often known in advance, although the price level of the maintenance depends on the market. General development of the economy and energy prices. Because of the stable nature of the maintenance, the number of employees in the road company is only a few compared to the size of the investment. The beta of the shares of the company is expected to be modest. Generally, in the road business, if one factor is would increase the volume of traffic the other would decrease it, there is an inverted cointegration behind two major factors.

If the energy is delivered through roads, the equation is different. The price of the energy is with present prices about half of the road pricing. Some of it goes to the energy company and some to the road company. Another factor is the variation in energy prices. They are cheaper in silent times due to the inertia of powerplants and client base. In the nighttime, robot trucks would be given an advantage in prices. Travelers, like Businessmen, would also get the leverage to travel during the nighttime in a steady office/camper instead of an airplane.

5 CONCLUSIONS

U.S. road trafficking has a price tag of over 2 trillion a year. The time used behind the wheel can be estimated at 60 billion hours annually with an average speed of 50 miles per hour and three trillion miles of travel. Average income is 19,4 trillion (2017) / 153 million (active population aged 15 – 64, Q2 2019 by Fred) 127 000 dollars a year. With average working hours of 1811 in a year, the rate is 70 dollars for an hour. About 4.2 trillion dollars, if credited as working hours. Half of the sum is about the same as the price of road trafficking. The sum reflects an identity level equilibrium between investments and earnings.

Often the driver of the vehicle experiences the vehicle as a continuum of himself. Autonomous services are not in the area at the same level. The choice to travel is different from today's modes of behavior. Also, price levels of energy and mechanical products are changing. They are affecting strongly on choices concerning vehicles. The throughput of the highway system gives inertia to increase in traffic. It is one pendulum of the development.

Every factor, or dimension, is changing. The pace of the development can be projected, but some features appear in the traffic sooner than others. The construction of tubes with sparse air concentrations would require different vehicles. Terrain models would not have airtight constructions for pressure changes. They are not having an air supply for passengers, and hazard in such an environment is severe. Vehicle renting agencies would be providing compartment vehicles for tube and terrain capability, with price levels of a premium class in the beginning.

Technologies are just now reaching the level for the integration of all devices in the metropolitan area. It is a requirement for a real smart city system. An avatar acting as one unit to each person in the city, or globe. Figure 34 shows the rapid development in the number of scientific papers published on the issue.

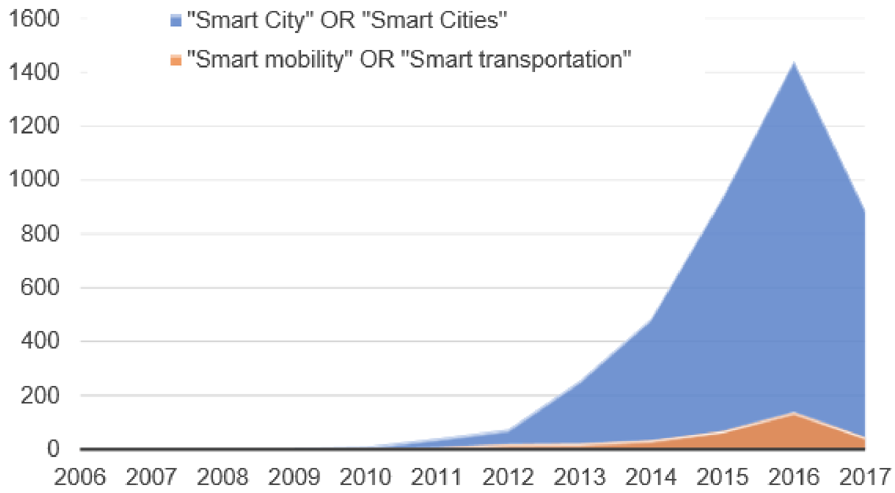


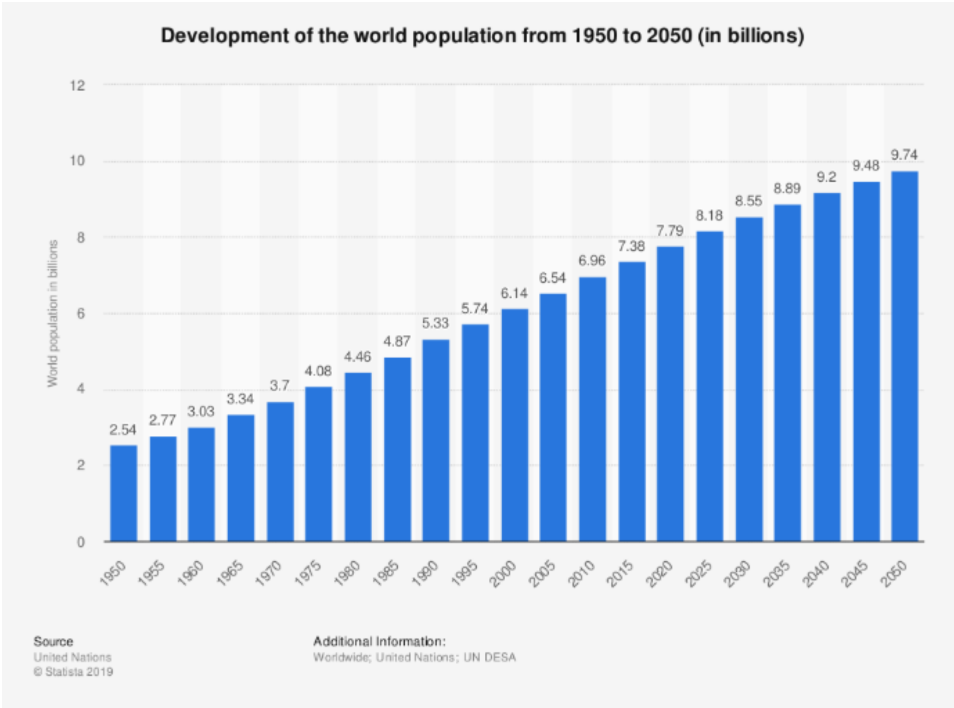
Figure 34. Number of published and proceeding papers smart cities and smart mobility. (Polytechnique Montreal, 2018)

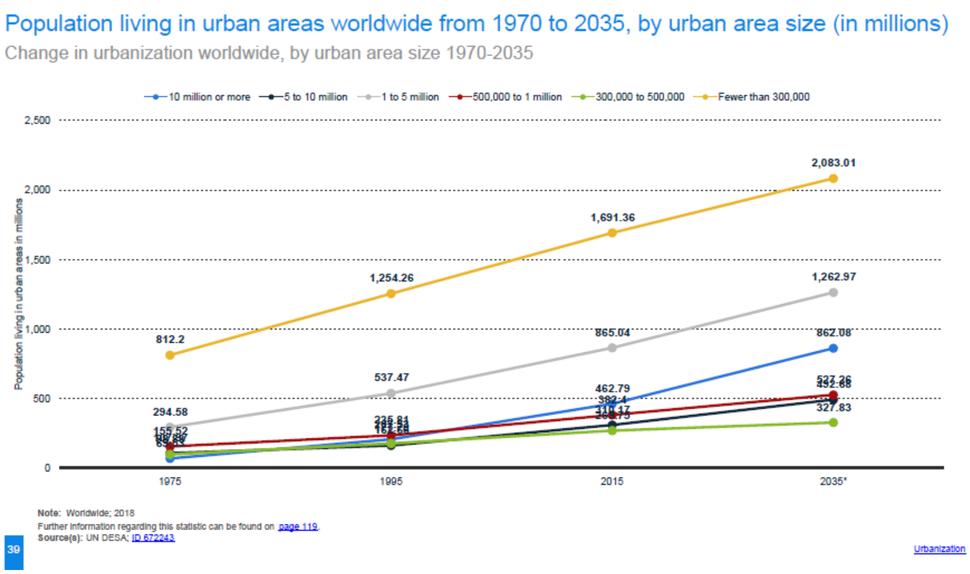
An ATMS is one expression of the smart city ideology. People in the city are analogous to vehicles. Products and services people are interested in can be processed like free lane-time segments on the road.

A smart city system is a generalization of an ATMS. It is capable to trade every service or product in the market. Each product of each store would potentially be part of the selection accessible to the client of the system. Every IoT, abbreviated from the Internet of Things, device connection would be a service as well. A user with access rights would be allowed to it.

A generalized system would be a surface layer of the network in general. Services of the city are like driver programs in the programmable systems. A smart city system provides a connection to services of the city, just like an operating system provides a connection to the services of computers and IoT devices. A connection is like a taxi, which may appear, because of a smart city system hailed the provider.

If trends of the day continue as expected, driverless technologies are a standard around 2050. The population of the earth is then about 10 billion, and the number of metropoles with the population over 10 million is considerably higher (Statista_WPOP 2019; Statista_URB 2019). In figures 35 and 36 are statistics about the projected development of the population. The average density of populations of metropoles is also higher, providing for a valid smart city concept.





Figures 35 and 36. Development of the world population and number of urbanizations by the size. (Statista_WPOP 2019; Statista 2109; Statista_URB 2019)

The density of the services population increases with the density of the client population. The same is true also with other resources of the development, they are generally increasing with populations. The general accessibility of resources is also improving, allowing the prime motor, i.e. population density, to get stronger. This equation is feeding itself, which is a common feature of every living organism, and it holds for time being.

LIST OF REFERENCES

CEN, 2019. CEN/TC 278: Intelligent transport systems, European Committee for Standardization, ,[Referenced 08.09.2019] from https://www.itsstandards.eu/

CNET 2019. 5G IS REAL AND LIGHTNING FAST: HERE'S EVERYTHING YOU NEED TO KNOW, [Referenced 21.08.2019], from https://www.cnet.com/news/5g-is-real-and-lightning-fast-sometimes-heres-everything-you-need-to-know/

Dalio R., 2019. The 3 Big Issues and the 1930s Analogue, Ray Dalio 2.9.2019. [Referenced 30.9.2019] from https://seekingalpha.com/article/4289151-3-big-issues-1930s-analogue

EIA_Con, 2019. Use of oil 2017, [Referenced 21.08.2109], from https://www.eia.gov/energyexplained/index.php?page=oil_use

EIA_ETOT, 2019. U.S. primary energy consumption by energy source, 2018, [Referenced 30.08.2109] from https://www.eia.gov/energyexplained/us-energy-facts/

EIA_PR, 2109. Weekly Retail Gasoline and Diesel Prices,[Referenced 20.9.20199 from https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm

Elswick F, 2016. How Much Does It Cost to Build a Mile of Road, [Referenced 2.8.2019] from https://www.blog.midwestind.com

Faming S, Xinqing W, Fanjie M, Ting R, Dong W, Jian T, 2018. Real-Time Traffic Sign Detection and Recognition Method Based on Simplified Gabor Wavelets and CNNs, Department of Mechanical Engineering, College of Field Engineering, Army Engineering University of PLA; Nanjing 210007, China

FHWA_detect, 2019. A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems, [Referenced 26.09.2019] from: https://www.fhwa.dot.gov/policyinformation/pubs/vdstits2007/vdstits2007.pdf

FHWA, 2018. Highway Statistics 2017, [Referenced 21.08.2109] from https://www.fhwa.dot.gov/policyinformation/statistics/2017/

FHWA_FUNCT, 2019. PUBLIC ROAD AND STREET LENGTH, 1980 - 2016
MILES BY FUNCTIONAL SYSTEM

NATIONAL SUMMARY, [Referenced 3.10.2019] from https://www.fhwa.dot.gov/policyinformation/statistics/2016/hm220.cfm

FHWA_revenues, 2019, Government Revenue Sources for Highways, 2000–2010,[Referenced 30.08.2019] from https://www.fhwa.dot.gov/policy/2013cpr/chap6.cfm#2

FHWA_spread, 2019, distribution of capital expenditures by type and functional system, [Referenced 30.08.2019] from https://www.fhwa.dot.gov/policy/2013cpr/chap6.cfm#2

FHWA, 2019, Traffic Volume Trends - December 2018, [Referenced 21.08.2109]from https://www.fhwa.dot.gov/policyinformation/travel_monitoring/18dectvt/18dectvt.pdf

FHWA_types, 2019, Hierarchy of Our Highway System, [Referenced 30.08.2019] from https://www.fhwa.dot.gov/policyinformation/pubs/hf/pl11028/chapter1.cfm

FHWA, 2015, Highway Investment Analysis Methodology, [Referenced 19.08.2019] from https://www.fhwa.dot.gov/policy/2015cpr/appendixa.cfm

FHWA_Traff, 2019, Individual Monthly Motor Vehicle Travel in the U.S. for December 2018, [Referenced 21.08.2019] from https://www.fhwa.dot.gov/policyinformation/travel_monitoring/18dectvt/page3.cfm

Frank E., 2018. How much does it cost to maintain a mile of road, [Referenced 19.08.2019] from: http://www.blog.midwestind.com/much-cost-maintain-mile-road/

Iovescu C, Rao S, 2017. The fundamentals of millimeter wave sensors, [Referenced 20.9.2019] from http://www.ti.com/lit/wp/spyy005/spyy005.pdf, 2017, Texas Instruments Incorporated

Ishida T, Isbister K, 1999, Digital Cities: Technologies, Experiences, and Future Perspectives, [Referenced 16.09.2019] from https://link-springer-com.ezproxy.cc.lut.fi/book/10.1007%2F3-540-46422-0

JSAE, 2019, ITS Standardization Activities in Japan 2018, [Referenced 22.08.2019] from http://hq.jsae.or.jp/its/ITS_broucher_en.pdf

Lindsey R, 2019, Climate Change: Atmospheric Carbon Dioxide, [Referenced 16.09.2019] from https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

Liu H, Li N, Guan D, Rai L, 2018. Data Feature Analysis of Non-Scanning Multi Target Millimeter-Wave Radar in Traffic Flow Detection Applications, published online 2018 Aug 21 in Sensors(Basel) [Referenced 19.9.2019] from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6163393/

NASA 2019, Annual Temperature anomaly, Earth observatory NASA, [Referenced 30.09.2019] from https://earthobservatory.nasa.gov/world-of-change/DecadalTemp

McKinsey&Company, 2016. Automotive revolution – perspective towards 2030How the convergence of disruptive technology-driven trends could transform the auto industry, Advanced Industries, January 2016, Copyright © McKinsey & Company, www.mckinsey.com

MTO, 2019, ABOUT MTO COMPASS, [Referenced 21.08.2019] from http://www.mto.gov.on.ca/english/traveller/trip/compass.shtml

Pennwell Corporation 2017. Vision Systems Design [Referencred 12.06.2017]. Available: http://www.vision-systems.com/articles/print/volume-17/issue-4/departments/leading-edge-views/3-d-imaging-advances-capabilities-of-machine-vision-part-i.htm

PEW TRUSTS, 2019, Funding Challenges in Highway and Transit: A federal-state-local analysis,en Referenced 20.08] from https://www.pewtrusts.org/en/research-and-analysis/articles/2015/02/24/funding-challenges-in-highway-and-transit-a-federal-state-local-analysis

Polytechnique Montreal, 2018. Smart Cities and Integrated Mobility, a white paper, [Referenced 22.8.2019] from https://static1.squarespace.com/static/596fb16003596e0fa70a232f/t/5b2a66c1f950b7e54549e35a/1529505474136/Smart-City-and-Integrated-Mobility-White-Paper-June-2018.pdf

Railfreightforward, 2019, 30 by 2030 – Rail Freight strategy to boost modal shift, a white paper, [Referenced 1.8.2019] from https://www.railfreightforward.eu/sites/default/files/usercontent/white_paper-30by2030-150dpi6.pdf

Sikora-Fernandez D., Stawasz D., 2016. THE CONCEPT OF SMART CITY IN THE THEORY AND PRACTICE OF URBAN DEVELOPMENT MANAGEMENT,[Referenced

31.08.2019] from https://www.researchgate.net/publication/304570582_THE_CONCEPT_OF_SMART_CITY_IN_THE_THEORY_AND_PRACTICE_OF_URBAN_DEVELOPMENT_MANAGEMENT

StackOverFlow, 2019, Gabor filter bank demonstration, [Referenced 2.10.2019] from https://stackoverflow.com/questions/20608458/gabor-feature-extraction

Statista_AFT, 2019, Size of the U.S. automotive aftermarket from 2008 to 2020, from https://www.statista.com/statistics/323192/automotive-aftermarket-size-in-the-united-states/

Statista_EP, 2019, Energy production in United States, [Referenced 18.9.2019] from https://www-statista-com.ezproxy.cc.lut.fi/study/48975/energy-production-in-the-united-states/

Statista_FUEL, 2019, U.S. motor gasoline and distillate fuel oil consumption by the transportation sector from 1992 to 2018 (in 1,000 barrels per day) , https://www.statista.com/statistics/189410/us-gasoline-and-diesel-consumption-for-highway-vehicles-since-1992/

Statista_HWC, 2019, Value of federal highway and street construction put in place in the U.S. from 2008 to 2018 (in million U.S. dollars), [Referenced 5.10.2019] from https://www.statista.com/statistics/615654/us-federeal-construction-spending-on-highways-and-street-projects/

Statista_GPR, 2019, Retail price of gasoline in the United States from 1990 to 2018, [Referenced 5.9.2019] from https://www.statista.com/statistics/204740/retail-price-of-gasoline-in-the-united-states-since-1990/

Statista_MC, 2019, Revenue by segment in the Passenger Cars market, from https://www.statista.com/outlook/1000000/109/passenger-cars/united-states#market-volume

Statista_NVEH, 2019, New light vehicle registrations in the United States from 2002 to 2018 (in million units) [Referenced 7.9.2018] from https://www-statista-com.ezproxy.cc.lut.fi/statistics/274929/new-vehicle-registrations-in-the-united-states/

Statista_TONMLS, 2019, Total U.S. ton-miles of freight from 1990 to 2045 (in trillions)*, [Referenced 6.10.2019] from https://www-statista-com.ezproxy.cc.lut.fi/statistics/185872/total-us-ton-miles-of-freight-since-1980/

Statista_URB, 2019, GLOBAL MEAGA TRENDS, [Referenced 7.9.2019] p. 39 from https://www-statista-com.ezproxy.cc.lut.fi/study/41271/global-mega-trends/

Statista_WPOP, 2019, Development of the world population from 1950 to 2050 (in billions), [Referenced 7.9.2019] from https://www-statista-com.ezproxy.cc.lut.fi/statistics/262875/development-of-the-world-population/

Statista_TAX, 2019, U.S. gasoline motor fuel taxes in July 2019,from https://www.statista.com/statistics/323192/automotive-aftermarket-size-in-the-united-states/

Statista_VEH 2019, Number of motor vehicles registered in the United States from 1990 to 2017 (in 1,000s), [Referenced 2.8.2019] from https://www.statista.com/statistics/183505/number-of-vehicles-in-the-united-states-since-1990/

Tripsavvy, 2019, Most crowded places in china, [Referenced 9.8.2019], Available: https://www.tripsavvy.com/the-most-crowded-places-in-china-4147740

UN_WPOP, 2019, WORLD POPULATION. projected world population until 2100 [Referenced 6.10.2019] from https://www.un.org/en/sections/issues-depth/population/

US DOT, 2019. ITS Standards Program , [Referenced 2.8.2019] from https://www.pcb.its.dot.gov/itscourses/default.aspx

US_DOT_trm_I101, 2019, MODULE 1. I101: Using ITS Standards: Systems Engineering Process, [Referenced16.8.2019] https://www.pcb.its.dot.gov/StandardsTraining/mod01/Module01.aspx?ModuleID=11&SubscriberID=689c74ff-aa92-48d8-9b81-3918f7f025cd

US_DOT_FREIGHT, 2018. Freight Facts and Figures 2017, [Referenced 08.10.2019] from https://rosap.ntl.bts.gov/view/dot/34923

US_DOT_its_depl, 2019, 2016-2017 Deployment Tracking Survey Results, https://www.itsdeployment.its.dot.gov/fm_surv.asp

US_Census 2019, Annual Estimates of the Resident Population for Incorporated Places of 50,000 or More, Ranked by July 1, 2018 Population: April 1, 2010 to July 1, 2018 - United States -- Places of 50,000+ Population

2018 Population Estimates, United states Bureau of the Census, [Referenced 30.9.2019] from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

US_EPA, 2019, Total U.S Greenhouse Gas Emissions by Economic Sector in 2017, United States Environmental Protection Agency, [Referenced 30.9.2019] from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

WikipediaPhA, 2019, Phased Array, [Referenced 2.10.2019] from https://en.wikipedia.org/wiki/Phased_array

World Road Association, 2019, ITS architecture, [Referenced 23.08.2019] from https://rno-its.piarc.org/en/systems-and-standards/its-architecture