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Overview of digital roadway infrastructure

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Bachelor's thesis
March 2021
Technology
Degree Programme in Logistics Engineering

Jyväskylän ammattikorkeakoulu
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Description

Author(s) Jalkanen, Jonne	Type of publication Bachelor's thesis	Date March 2021
		Language of publication: English
	Number of pages 41	Permission for web publication: x

Title of publication
Overview of digital roadway infrastructure

Degree programme
Logistics Engineering

Supervisor(s)
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Assigned by
Marko Forsblom, ITS Finland ry

Abstract

Intelligent transportation systems have become more and more important around the world due to urbanization, increasing traffic and mobility. The traffic systems must continually be developed more efficient, safer and ecologically sustainable than they are today. Digitalization, new innovations, real time data and development of the traffic systems are to some extent the solution.

The topic of the study was assigned by Marko Forsblom from ITS Finland. The aim of the study was to create an overview of digital roadway infrastructure. More precisely the objective was to find out from where the data can be collected, where it is stored and how the data can be utilized.

Method chosen to conduct the study was decided to be systematic literature review. The answers to the research questions were to be found from researches and projects related to intelligent transportation systems, roadway sensors and traffic data utilization and management. The study was made by using qualitative analysis of the collected material through comprehensive search from various different sources. Comparison between different types of material was conducted to find repeating similarities. First the bigger picture was formed and proceeding from there towards smaller parts of the road traffic systems was conducted.

As a result many types of roadway sensors were found. The functions of the sensors and the data acquired from the sensors were introduced. How the data collected from the sensors is utilized by many different actors was clarified. Also storing of the data by a variety of different actors was introduced.

Keywords/tags (subjects)

Miscellaneous (Confidential information)

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1 Introduction

Intelligent transportation system (ITS) has been an important topic in logistics and traffic systems. ITS seeks to make transportation, traffic and mobility more efficient, safer, sustainable and easy by bringing innovative solutions to traffic management systems. Today, developing the traffic system is even more important due to increased road traffic, congestions and emissions. Environmental issues, among them the global warming, are driving the ITS and its digitalisation. Digitalisation of the traffic system is increasing rapidly as we are going towards automation. Due to overall digitalisation of the world around us the availability and the amount of data and information has increased massively, so, how to utilize that is an interesting and important question. New innovations and ways to utilize the existing infrastructure by adding "intelligence" to them has taken huge steps because of technical development. Furthermore, nations growth depend on those kind of actions in the field of ITS. The transportation system must become continually more efficient, safe and reliable. (World road association.)

There are a lot of studies and projects related to digital roadway systems but they are focused on a certain problem or a small area of that. For example, the Nordicway project is about interoperability of cooperative ITS for passenger and freight traffic. (Scholliers, J. 2016). And the project is covering quite a lot of ground of digital roadway infrastructure but still focusing on just a part of that. Furthermore, most of the researches are focused on a certain sensor or a system of sensors such as traffic lights. Very few of the publications are overviews or dealing with wider perspective of the digital roadway infrastructure. Comprehensive studies of the roadway sensors have been done such as the Traffic Detector Handbook written by Klein, Mills & Gibson 2006 for the U.S department of transportation. This kind of combination of roadway detectors, sensors and data management study has not occurred in the wide range of searches. It is important for understanding and development point of view to have overall view of the digital roadway infrastructure.

The first idea of the thesis is to create some kind of overview of digital infrastructure but because of the scale of that topic the topic is delimited to digital roadway infrastructure. The information for the thesis is collected from the bits and pieces found from researches, articles, projects and books and then aggregated into an overview. The overview is created by setting three questions which to answer. The questions are:

1. From where the data can be collected?
2. Where the data is stored?
3. How the data can be utilized?

The topic of the thesis was introduced by the CEO of Intelligent Transportation Society of Finland (ITS Finland ry) Marko Forsblom.

> *Intelligent Transportation Society of Finland – ITS Finland is a forum for collaboration which brings together representatives from a wide range of governmental institutions, research and educational institutions as well as businesses to work for our common cause: building a safe, smooth and sustainable future.* (ITS Finland ry; A forum for smarter mobility).

“ITS Finland´s vision is a sustainable and user-centric approach to intelligent transportation systems...” and their mission is to make “...transportation safer, smoother and more efficient and sustainable.” (ITS Finland ry; Vision & Mission).

First, as a knowledge base the thesis introduces ITS as a wider perspective to the subject at hand. The data collection and its importance are handled next. Research methods will be introduced in chapter four (4). The main part of the thesis is the roadway traffic detectors. The section starts with roadway detectors as smaller pieces of the roadway infrastructure and proceeds to larger systems such as traffic lights. The roadway traffic detectors section also introduces the functions of the sensors and systems for better understanding how they can be d and how the data is extracted. In addition, projects are used as examples for answering the research questions. Finally the thesis is summarized, and conclusions and further ideas are discussed.

2 Intelligent transportation system

Intelligent transportation systems (ITS) are a system of an integrated communication and information technologies. ITS aim to improve the entire transportation system and the use of road network. ITS provide solutions for the transportation and traffic problems which commonly are congestion, safety and environmental issues. (World road association.)

For ITS to work there are many things to taken into consideration. First are the enabling technologies which are used to collect the information and data. They are the sensors used for detection and monitoring the status of the roadways. Next those components are linked together with the telecommunication network which enables the dissemination of the information and is connecting road users to the system for useful information. Then the data must be aggregated, analysed, processed and converted into understandable form. After that the information is disseminated through various channels such as dynamic message signs on roadways, phone applications, in vehicle display devices and websites. Lastly the data is archived and managed for the purpose of future planning and improving transportation, sharing with third parties and developing applications. ITS also commits several different stakeholders for a collaboration, integration and development of the system. For example, road authorities, ministries, the freight industry, telecommunication companies, city planning organisations and manufacturers of ITS products and cars are very much involved. (World road association.) Interoperability is the key word of ITS and not only between the stakeholders but also between the technologies for them to work seamlessly and bringing the desired benefits.

A good example of ITS development venture is the Aurora smart road and open testing ecosystem started in 2016. The venture seeks to explore how intelligent roadway property can be managed by new technologies in arctic conditions. From the projects related to the smart road experiment, authorities obtain information about the effects of smart traffic for developing the digital infrastructure. Projects related to the venture are testing what kind of new technology is needed for automated driving and ploughing. The data provided by the sensors is utilized for monitoring and management of the structure condition of the roadway. (Väylä 2019.) The Figure 1 shows an example how the data is obtained from various sensors installed in and alongside the roadway.

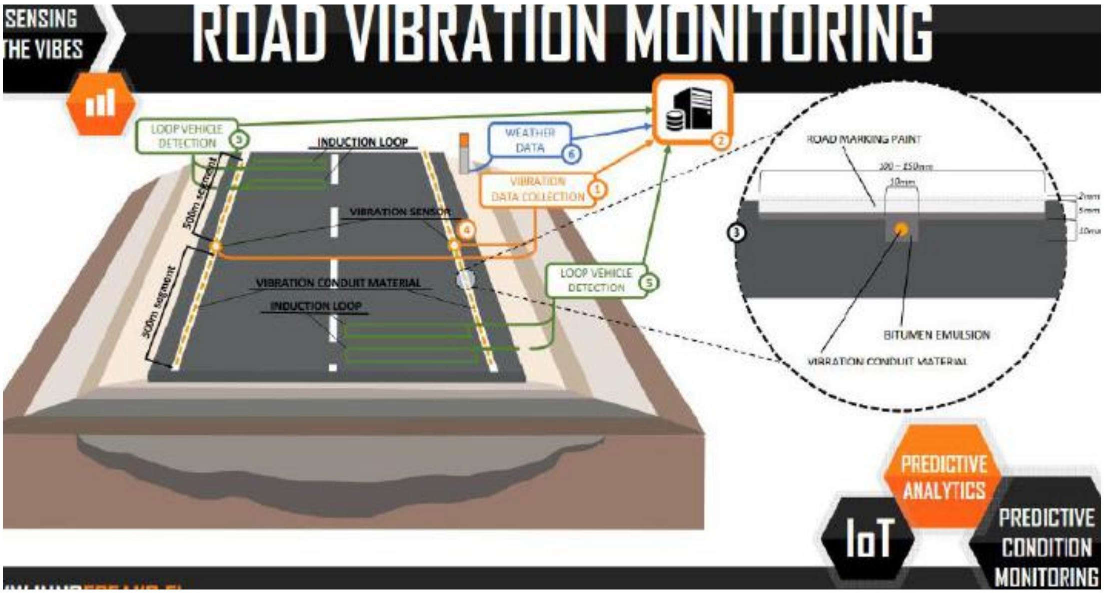

Figure 1. An automatic traffic measurement station (adapted from Väylä 2019)

At the Aurora smart road there are several new technologies used. On the 10 km test section there is 6 road side weather stations, 2 variable message signs, very accurate positioning service based on real time kinematic measurement, high definition machine readable 3D map including underground infra, automatic traffic measurement stations, intelligent ploughing signage and 5G network for communication services. All the elements mentioned form an intelligent transportation ecosystem of its own. (Väylä 2019)

3 Data

The data is information, facts and statistics aggregated from different sources. It has been said that the data is the new oil, very valuable and everyone in the market wants to have that as much as possible. The data has become merchandise and it is sold and purchased around the world. The importance of quality data is essential in decision making and development. The ITS to develop and to become more automated the data is crucial. Without the data and information the development is impossible. Consequently, the data acquisition plays key role in ITS. (World road association; data and information.)

A backbone of the data acquisition, storage, process and dissemination is the digital infrastructure which refers to the entire network of information technologies. It consists of the physical elements such as computers, servers, a wire and wireless data transmission and the sensors providing the data. (Spacey 2017.)

A prerequisite for intelligent transportation systems is the acquisition of a traffic data. The acquisition is done by various different sensors along the roadways. The means to acquire the data are the traffic detecting sensors, vehicles, crowd sourcing from social media networks, reports from mobile phones and the information from third parties such as emergency services, freight and road maintenance operators. After the data is collected it needs to be processed. In the processing the data is set to a proper format, cleaned from unreliable and invalid data, added a time stamp and location reference and integrated from different sources. (Chowdhury & Sadek.)

The traffic data is collected and stored by the traffic management authorities within a country. In Finland those organizations include the Finnish transport infrastructure agency and Fintraffic. The Fintraffic governs and manages the data and information collected from every transportation mode in the entire traffic system. The data is both real time and historical and open for everyone to use. The data is shared with an open interface which is called an application programming interface (API). Through the API´s traffic management organizations enable companies from various industries to enhance their operations and decision making. (Fintraffic.)

For example, retailers can use the data when deciding optimal store location according to people's mobility. Advertisers can utilize the data to when and where to advertise. City planners utilize the data in planning new roads and other infrastructure. Authorities use the data for detecting dangerous road sections and intersections and thus can make data driven decisions, for example to set speed limits or install traffic lights. Emergency services such as the police, ambulances and fire engines utilize real time traffic data for avoiding congested roads to arrive the destination quicker. In logistics the traffic data is crucial for managing the fleet operations. (Traffic data 2021.) The data enables effective route planning, efficient and economical fleet management. In the bigger picture the data is d for to meet the development requirements of the ITS. The field of transportation and mobility needs to reduce emissions and the use of energy and continually become more efficient and sustainable.

A good example of the data acquisition through a set of various sensors is the LuxTurrim5G project taking place at Espoo, Finland. The sensors are installed in novel light poles (Figure 2) which already are an essential part of the roadways anyway.

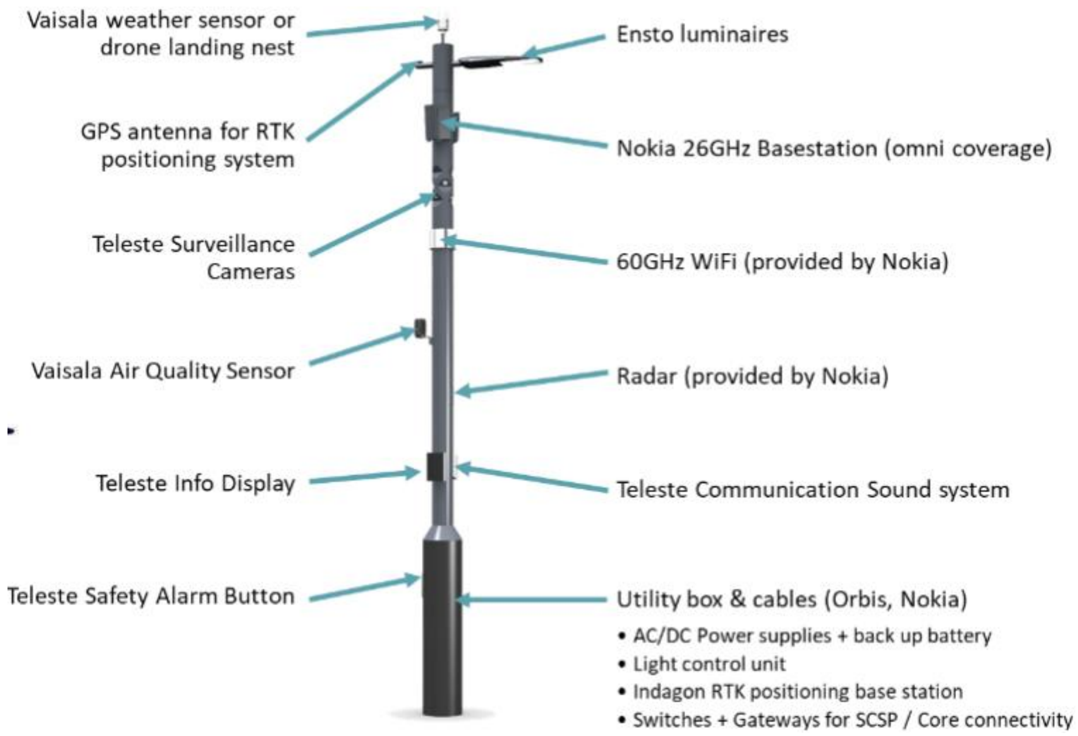

Figure 2. LuxTurrim5G smart light pole concept (adapted from Luxturrim5G ecosystem)

The aim of the project is to enable digital infrastructure for future smart cities. Other goal is to create an open data platform and a market place with the help of fast 5G network and the data acquisition from the smart poles. The data is managed locally inside a city because of easier control of it. The data is shared at an open interface for everyone to utilize. Especially new use cases, applications and business models are expected (Luxturrim5G ecosystem.)

4 Research methods

The selected type of research for the thesis is a literature review. The sub category of the research method is called a systematic literature review. (Xiao & Watson 2017.) The method was chosen because of the nature of the research requires qualitative analysis. The aim was to create an overview of a digital roadway infrastructure and that is done by aggregating and summarizing information from the other researches and publications. Furthermore, a certain topic and area for the research was selected, the search terms were chosen keeping an eye on the topic and three research questions were set. The questions are:

1. From where the data can be collected?
2. Where the data is stored?
3. How the data can be d?

The material was acquired by starting the search from bigger picture using search terms intelligent transportation system, digital infrastructure, digital traffic infrastructure and smart city. Thus understanding what is included and excluded from the overview and to narrow down the first suggested topic a digital infrastructure. To get into smaller components from which the digital roadway infrastructure is composed of and to answer the research question, where the data can be collected, the search terms were set as follows: traffic sensors, roadway sensors, traffic detection + sensors and traffic data collection methods. The searches were also done with the names of the sensors. Already those searches provided some answers to the question where the data is stored but also the term, road traffic data storage, was used. The term, road traffic data utilisation, was used for finding answers to the question how the data can be utilized. Furthermore, variations of the terms mentioned were used and other terms, such as, application, solution and smart were included. The searches were done in English and some in Finnish for additional view and to see how the systems in Finland work compared internationally and because there are several projects related to the topic going on in Finland.

The information was mostly gathered from the internet by the Google search engine. Scholarly online magazines and articles, expert articles, authorities (Finnish transportation infrastructure agency, EU etc.) and manufacturer's websites were used for acquiring the information. The JAMK university library database for books, articles and magazines was searched. A Jyväskylä university publication, Transport technologies, containing different related researches, helped in building the research and the ideas.

The quality of the material found is very good and matches the research questions well. The amount of the material is practically overwhelming. There are a lot of scientific researches done and projects in progress related to the ITS and the parts that it consists of. Intelligent systems are taken into use all the time and articles are published about them. A time span for the researches or the information was not set but the newer the better. Most of the material is published late in the 2010s and the latest articles can be found from scientific websites specialized in ITS.

The material was divided according to the research questions. The main part consists of the question from where the data can be collected, that is, the roadway detectors. The detectors were then divided into two groups, intrusive and non-intrusive sensors, followed by the other systems related to the question. The questions about data storage and utilisation were their own divisions sensor by sensor for both questions.

The material eventually chosen was compared with the other similar researches for an accuracy of the information. The material´s relevance to the topic and the research questions was analyzed. The material found was consistent with each other. No conflicts between them were detected, only different approaches and point of views.

5 Roadway traffic detectors

In this section the focus is on sensors mounted directly under the surface of the road and alongside or overhead the roadway. The part introduces the actual sensors, their applications and the information and the data the sensors provide. The sensors or traffic detectors can be classified into two groups, intrusive and non-intrusive (explained in chapter 5.2), by their function and the way of installation required (Yu, Prevedouros 2013, 45).

5.1 Intrusive sensors

Intrusive traffic detectors are installed under the surface of the road or right on the surface of the road. The detectors require a physical contact with the road to operate. They sense the change in the status of the sensor to detect the vehicle. (Yu, Prevedouros 2013.)

5.1.1 Inductive loop detector

Inductive loop detectors are very commonly used for vehicle detection because of their reliability. They are mainly used for detecting a vehicle presence and passage. The presence is detected while a vehicle is stopped over the sensor and the passage while a vehicle is moving. The operation of the inductive loop detector is based on detecting a change in the magnetic field when a vehicle or a metal object comes above the copper wires embedded in the road. The system consists of four main parts: an underground wire loop, a lead-in wire from the loop to a pull box, a lead-in cable from the pull box to controller and an electronics unit housed in the controller as shown in Figure 3 (Klein, Mills & Gibson. 2006.) The electronic unit gathers the data acquired from the sensor and sends it forward to a traffic management centre for further processing and analysing. Versatility of these detectors is a significant factor for their wide usage. The information the inductive loop detector provides can be the amount of vehicles in traffic, usually vehicles per certain time period (e.g. vehicles/hour), speed detection, vehicle classification by axle count and the presence of the vehicle. Of course, every application needs different setup. (Klein, Mills & Gibson. 2006.)

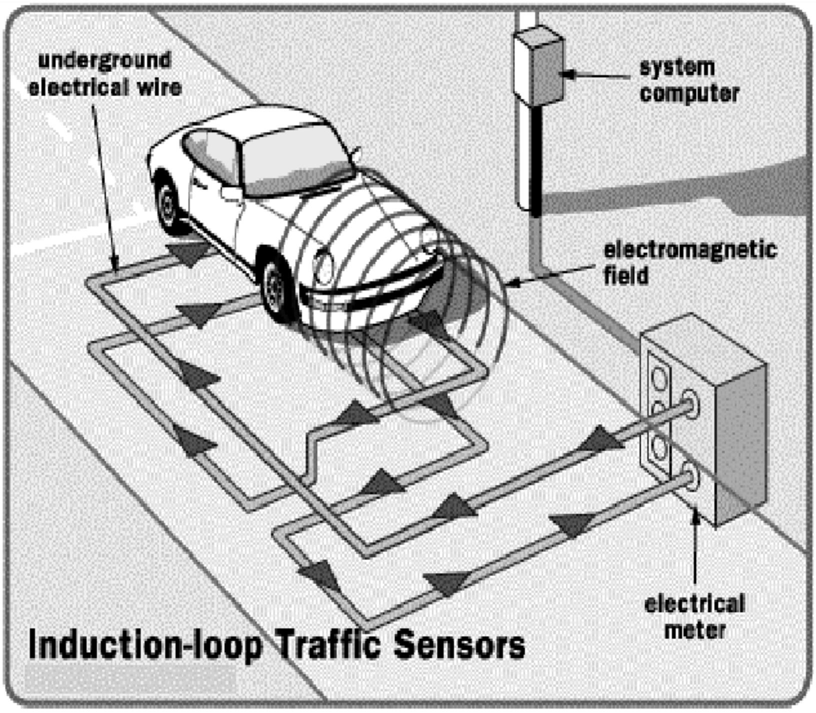

Figure 3. Inductive loop detector´s simple basic layout (adapted from Hegadi 2014)

The inductive loop detectors are mainly used in intersections with traffic lights. They provide information about a vehicle presence and that the vehicle is approaching the intersection for the traffic lights to change sequence. Detecting the presence of a vehicle is used for example in car parks to open doors or gates. The data collected is for a traffic management to use in planning the infrastructure, managing the traffic to make it more fluent and sharing the information about congestion or accidents detected. . (Klein, Mills & Gibson. 2006.)

5.1.2 Pneumatic road tubes

The operation of pneumatic road tubes is based on detecting the pressure caused by a vehicle driving over the tube. The tube is squeezed by the axle load of a vehicle and peak in air pressure is detected by a data logger on the other end of the tube. The other end of the tube is sealed. Pneumatic tubes are installed in the road across the lane. They are usually used for temporary traffic surveillance and data gathering in low traffic roads. The pneumatic tubes are used for a vehicle counting and a classification by axle count, measuring a speed and an intersection stop delay. (Mimbela & Klein 2007, chapter 4.)

5.1.3 Magnetic detectors

Magnetic sensors detect the disruption in the earth´s magnetic field when a vehicle passes by. A single magnetic sensor does not detect a presence of a stopped vehicle the way the inductive loop detectors do. They are very robust and durable, and because of that they are used in harsh environments. The preferred installation is under the roadway from the side of the road as seen in Figure 4 but other methods are used for different purposes and sensor models. (Klein, Mills & Gibson. 2006.)

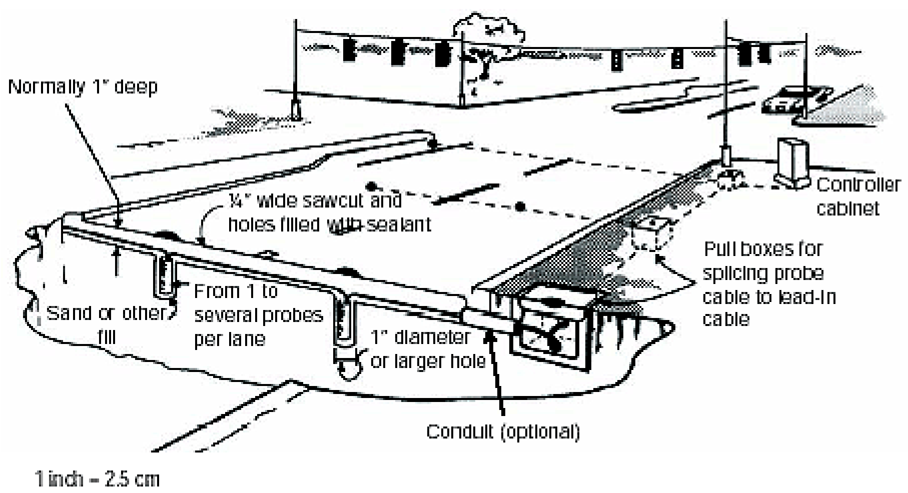

Figure 4. Magnetic sensor installation (adapted from Klein, Mills & Gibson 2006)

The magnetic detectors are used because of their accuracy, low cost, sensitivity and because they provide the data fast. The sensors can provide information such as vehicle count (traffic volume and density), speed and roadway occupancy, classification of a vehicle and length of the vehicle. The sensors are used for controlling the traffic lights and generally in the roadways to provide the data for a traffic management. (Klein et.al. 2006; Urbiotica. Wireless magnetometer sensor for traffic management.) The data is utilized same way as the inductive loop detectors. (See chapter 5.1.1)

5.1.4 Piezoelectric sensor

Piezoelectric sensor is installed diagonally under the road surface. It consists of the sensor and an electronic unit for saving the data. The sensor reacts to a pressure caused by an axle of a vehicle passing over the sensor and converts the mechanical change into an electrical output. The piezoelectric sensors can be used for vehicle counting, classification of vehicles and detection of a speed, width and weight (Klein, Mills & Gibson 2006.) And for example the Aurora smart road project uses piezoelectric sensors to sense vibration of the road to determine from the data collected the stress and wear caused to the road structure (Väylä 2019).

5.1.5 Weigh in motion

Weigh in motion (WIM) is a system constructed using the sensors introduced in previous chapters, usually the piezoelectric and the inductive loop sensors, as seen in Figure 5. Instead of the piezoelectric sensors the system can be constructed using bending plates or load cells. (Zhang, Haas & Tighe. 2007, 3-5.)

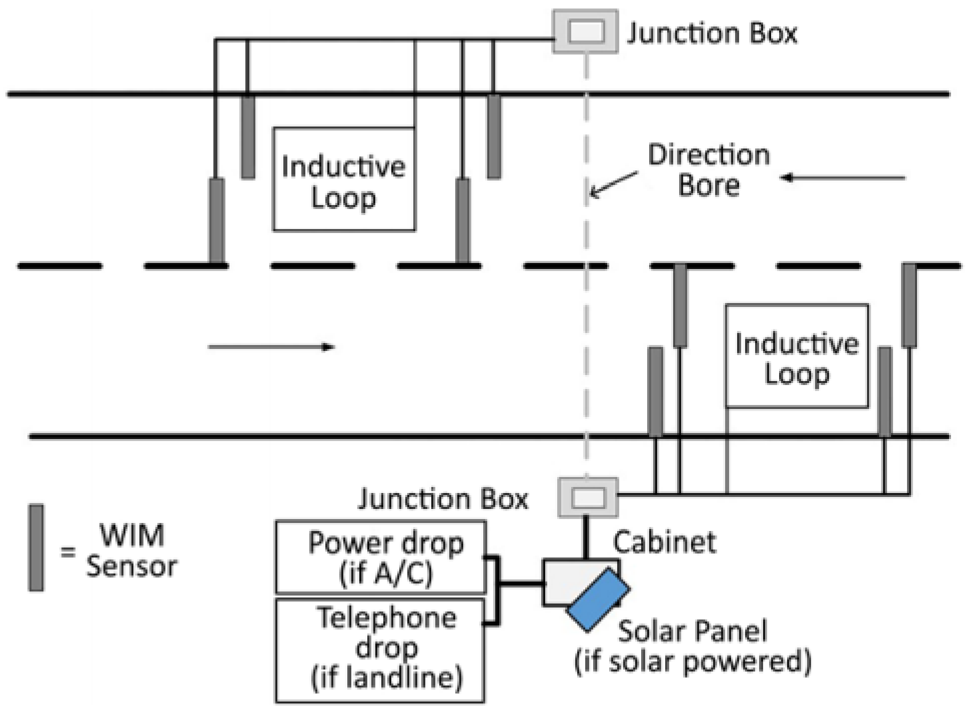

Figure 5. Typical 2-Lane Bidirectional WIM System Design (U.S. Department of Transportation 2018)

The WIM system consists of weighing sensors, an electronics unit in the side of the road which is containing a data processing unit, data storage and communication devices (Figure 5). Van Loo & Znidaric (2019, 12) define the system as follows:

> *Weighing-in-motion is generally defined as the process of measuring the dynamic tyre forces of a moving road vehicle (dynamic wheel loads) and estimating the gross vehicle weight (GVW) and the portion of that weight carried by each wheel, axle, and axle group of a corresponding static vehicle (static wheel and axle loads).*

In addition to weight, other information is also recorded when a vehicle passes the WIM system. That information is called vehicle record and it consists of:

- *Unique record number*
- *Location of WIM system including the lane and direction of travel*
- *Date and Time of passage*
- *Vehicle speed*
- *Axle distances*
- *Wheel base and/or Vehicle length*
- *Vehicle classification*

(Van Loo & Znidaric 2019, 65)

Overall long term traffic data such as amount and distribution of vehicles is also recorded. The WIM system is an application of different sensors for an automatic measurement and a collection of data. There are several ways of measuring the WIM depending on the use and information required. (Van Loo & Znidaric 2019.)

A static weighing is not related to motion, but still important, as it usually is the official weighing method, and its results are used as a reference for the WIM systems. The static weighing is used by the police and toll. A low speed WIM (LS-WIM) is used in a controlled area beside the road. Like the name tells, the speed of the vehicle weighed is low, about 8 to 15 km/h. In high speed WIM (HS-WIM) station the measurement is done amongst normal traffic in an open roadway with a normal speed. A dynamic on-board WIM (OBW) is a weighing system installed in the vehicle. The system constantly measures the gross vehicle weight, axle and tyre loads. That data can be linked to a location (GPS) and stored from the entire transportation time. In a bridge WIM (B-WIM) the sensors are mounted under the structure of a bridge. The B-WIM collects the vehicle record data but also significant information about the behaviour of the bridge structure such as bending, caused by vehicles. The data can be used for assessing the condition and safety of the bridge. A stress in motion (SIM) system is used for measuring tyre contact stresses to the road surface. The resulting data can be used for a pavement design, detailed vehicle classification, tyre management and road safety applications. (Van Loo & Znidaric. 2019, 12-14.)

The information the WIM systems provide is important for applications in transportation studies that plan and optimize the future road network. The vehicle and traffic loading information helps to plan the maintenance of existing road infrastructure and managing the traffic flows in the road network. The information is used for weight enforcement to achieve better compliance with the loading regulations. The WIM industrial applications are used at ports, industrial and logistics centres and use the system to check the weights and axle loads of the trucks to prevent overloading. (Van Loo & Znidaric. 2019, 15.)

5.2 Non-intrusive sensors

Non-intrusive sensors are quite the opposite of the intrusive sensors which area sub surface mounted. The non-intrusive sensors or detectors are mounted above ground, over-head or on the side of the roadway. They can detect the vehicle from a distance with many different angles. The detection zone can be wide or long and cover multiple lanes. The detectors used are microwave radar, infrared sensor, acoustic sensor, radar, lidar, video image processor and environmental sensors (Yu & Prevedouros 2013.)

5.2.1 Microwave radar sensor

The microwave radar sensors transmit continuous low energy high frequency signals and the reflected signal from a vehicle is then analysed. A change in frequency indicates that there is a vehicle in motion. The microwave radar directs the signals at the roadway to calculate the time delay of the reflected signals and thereby detects the vehicle as seen in Figure 6. The detector can be mounted overhead in bridges, over lane traffic sign structures, poles, masts or on side of the road. (Klein, Mills & Gibson 2006.)

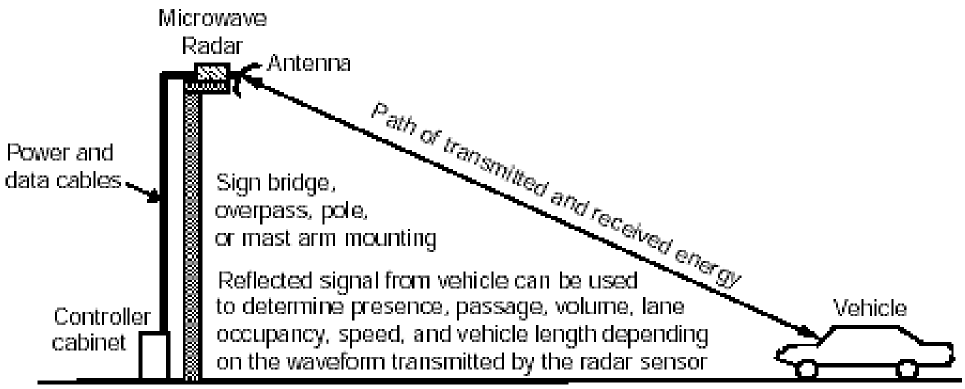

Figure 6. Microwave radar operation (Klein, Mills & Gibson 2006)

There are two types of microwave radars used in traffic management applications. Continuous wave radar transmits signal continuously at a constant frequency. This type of radar cannot detect a stopped vehicle. Frequency-modulated continuous wave radar transmits alternating frequency which changes the waveform constantly, thus is capable of detecting a stopped vehicle. The traffic data the microwave radar provides can be lane occupancy presence, passage, speed, classification and count of vehicle. (Klein, Mills & Gibson 2006.) Applications for the microwave radar sensors are for example a traffic light intersection control, queue detection, roadway traffic management, incident detection, recording statistical data and even pedestrian detection waiting at crosswalk.

5.2.2 Ultrasonic sensor

An Ultrasonic sensor works like the microwave sensor with the difference of transmitting sound pulses instead of high frequency. The sound pulses beyond human hearing are transmitted and received back from the object. Then the time difference between a reference target and the object is calculated and the result is a distance to an object. (Jeon, Kwon & Jung 2015.) The sensors are usually mounted above the lane for vehicle detection but applications of side of the road and diagonal installation can be used as seen in figure 7.

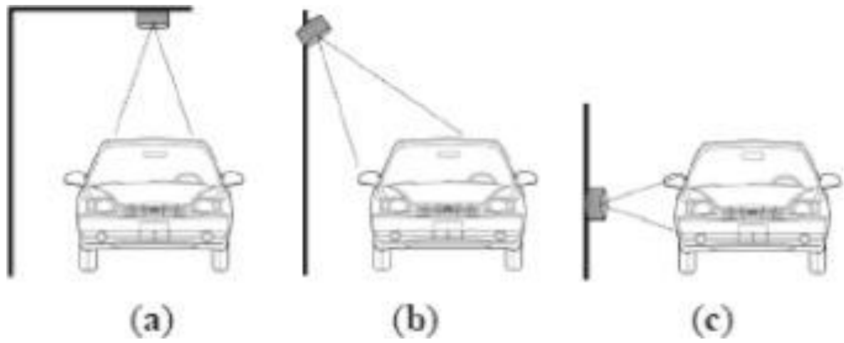

Figure 7. Ultrasonic sensor installation examples (adapted from Jo & Jung 2014)

The ultrasonic sensors can detect presence, distance and measure speed of a vehicle. Speed measuring requires two sensors 5 meters apart. The most used applications are related to a traffic flow, such as vehicle count and vehicle presence detection in traffic light intersections. Common application can be found from parking garages. The ultrasonic sensor is mounted in the sealing of each parking slot. The situation is depicted in Figure 7. (a). The sensor measures the distance to a floor, and when a vehicle is driven under the sensor, the measured distance shortens and red light is turned on indicating occupied. (Jeon, Kwon & Jung 2015.)

5.2.3 Acoustic sensor

Acoustic sensor is basically a set of microphones. The sensor detects sounds of vehicles passing by the detection zone, such as engine noise, tyre noise, exhaust noise etc. The detection zone can cover multiple lanes. Sounds arrive to the sensor in different angles, thus they can be detected separately. The acoustic sensor is typically mounted on side of the road structures as seen in Figure 8.

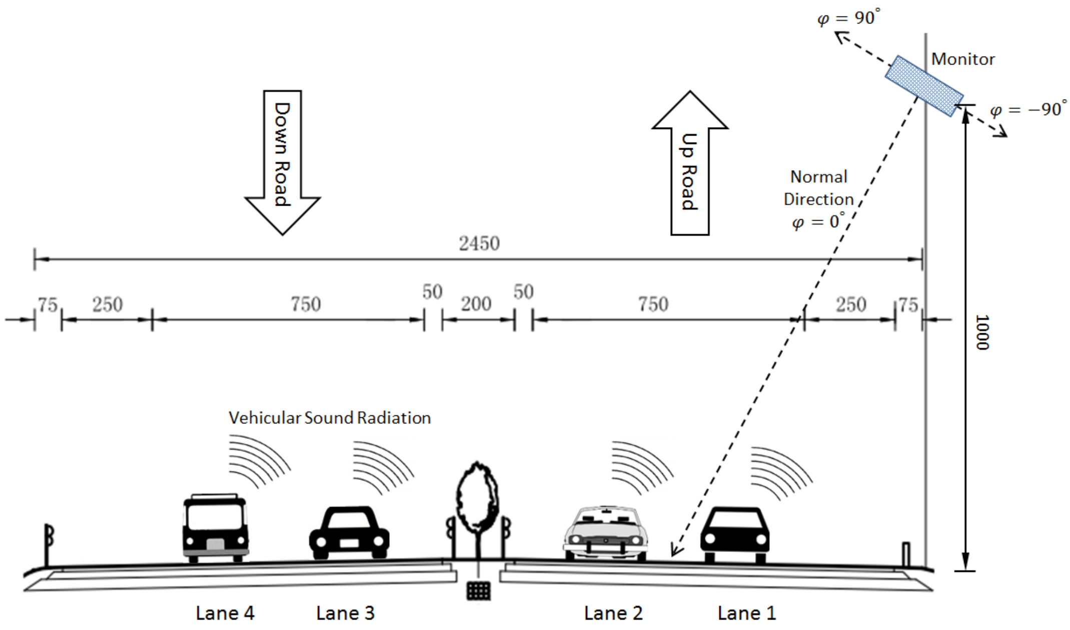

Figure 8. Multiple lane acoustic detection (adapted from Na 2016)

The sounds detected by the sensor are converted to digital form by using a programmable digital signal processor. Acoustic sensors can be used for to detect presence, classification and speed of the vehicle, for to measure traffic volume and roadway occupancy. (Na, Guo & Fu. 2015.)

5.2.4 Infrared sensor

Infrared sensors are mounted over the road to detect the traffic flow as depicted in figure 8. There are two types of the infrared sensors, passive and active.

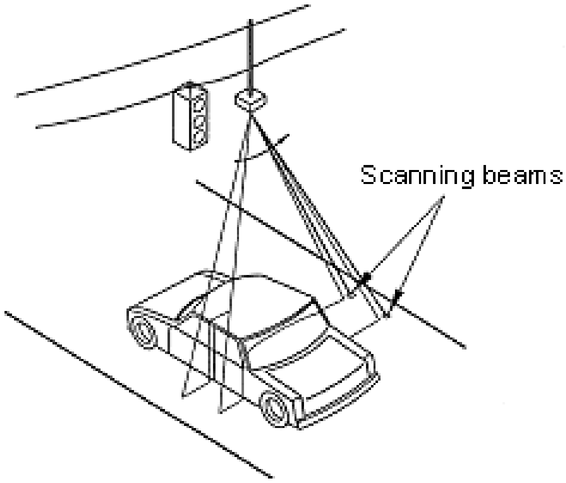

Figure 9. Infrared sensor scanning (adapted from Klein, Mills & Gibson 2006)

A passive infrared sensor does not transmit any energy itself. Instead, it detects the energy emitted by the target such as a vehicle and road surface. The change in the emitted energy is detected when a vehicle enters the sensors field of view. There are several different types of the passive infrared sensors. They can be used for detecting presence of a vehicle, vehicle counting and speed measurement and also classification by length, occupancy detection, and queue detection depending on their design. There are also multi-channel and multi-zone passive infrared sensors which can provide the functionality of two inductive loop sensors as they measure speed, vehicle length, traffic volume and lane occupancy. (Mimbela & Klein. 2007.)

Active infrared sensors emit an infrared energy beam to detection zone, and the time from the sensor to an object and back is calculated. The object is detected if there is a change in the time compared to reference time. Active infrared sensors can be used for detecting presence of a vehicle at traffic signals, traffic volume, speed measurement, length assessment, queue measurement and classification of vehicle (Mimbela & Klein. 2007.) Furthermore, the sensors work well for example in tunnels since they are sensitive to weather conditions such as fog and precipitation and the sensors are able to detect engine over heating or fire.

5.2.5 Radar

Radio detection and ranging, better known as radar, is a sensor transmitting radio waves. The time between transmitted and reflected radio waves from the targeted object is measured. The results of the measuring can be presence, speed, location, distance, size, shape and even image of an object. With the newest radar technology it is possible to follow multiple lanes, up to 256 vehicles simultaneously and even with a range of 300m. The most known traffic enforcement application is police radar trap. At intersections the radar is used for traffic light management, queue length detection, stop line detection and pedestrian detection. For the traffic management the radar provides traffic counting, road occupancy, vehicle classification data, statistics and statistical analysis. (The most advanced radar technology 2020.) Furthermore, the data can be transferred to the traffic management centre in real time or statistic data can be manually collected on demand and also automatically in certain time periods for further analysis.

5.2.6 Lidar

Lidar comes from the words light detection and ranging. As the name depicts the lidar emits light pulses which then are reflected back from an object and therefore is able to detect the distance. Since the lidar can send up to 150, 000 light pulses per second to a desired area from narrow to 360 degrees it is able to construct an accurate 3D image from the scanned area. The imaging feature of the lidar is used to classify vehicles in traffic and at the same time the speed can be detected. A section of a road and intersection behaviour can be analysed by the data gathered from the lidar application. (Taylor-Smith 2019.) As Vickers (2020) writes about an experiment conducted by Hao Xu, who explained "...LiDAR sensors can convert vehicle data into information about vehicle and pedestrian trajectory". "The program can identify when and where speeding is occurring, for example, and it can provide a time-space diagram, showing how vehicles slow down, stop, speed up and go through an intersection during a light cycle.". The lidar system can therefore be used for detecting near-crash situations. Lidar system can identify different road users, monitor and manage the intersection automatically as visualized in Figure 10.

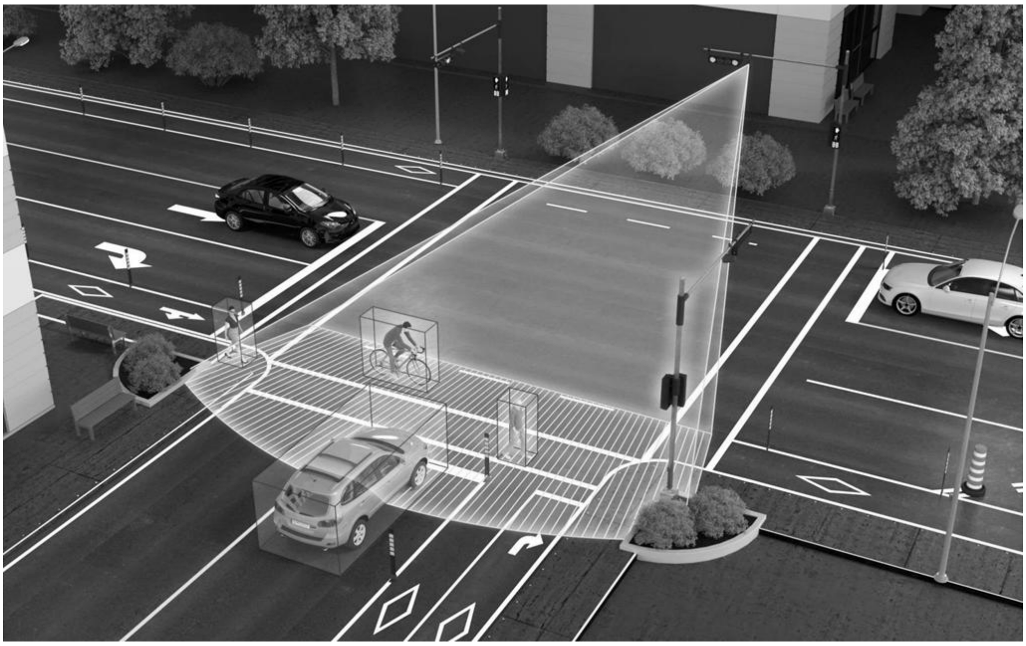

Figure 10. Lidar monitored intersection (adapted from Dinesh 2019)

5.2.7 Video image detection

Video cameras are used as video image detectors by the traffic management centres. Together with an assistance of human video image processor (VIP) system is an effective tool for traffic surveillance and management. The VIP system consists of cameras, computer which digitalises and processes the video feed and software that interprets the video feed and converts it to traffic data. The VIP system can provide a real time data about traffic flow rate, occupancy, a vehicle classification and speeds extracted from multiple lanes. There are various applications in which the VIP system can be used for. The traffic lights can be controlled automatically by the VIP by detecting a vehicle entering the detection zone and then changing the lights accordingly. Variable message signs (VMS) can be controlled with the system. For example, when congestion, incident or other disruption in the traffic is detected the VMS message is changed. A vehicle tracking and travel time estimation is also possible. Observing the roadway weather conditions is an important usage of VIP system. (Klein, Mills & Gibson 2006.)

5.2.8 Environmental sensors

Environmental sensors can be intrusive or non-intrusive depending on the information and data required. Some of the sensors discussed in earlier chapters are used but more precise function sensors are also used. The road surface conditions can be monitored with both the intrusive and non-intrusive sensors such as camera, infrared and laser based sensors or road embedded sensors. Additionally, the sensors can be integrated in a vehicle to collect information along the roadway. The sensors need to provide information about the status of the road whether it is dry, wet, frozen or covered with snow. The data gathered from the surface of the road is temperature which can also be measured underneath the surface to get additional information about the road conditions. The temperature is used to determine the grip on the road, more precisely the friction of the road surface is calculated. Furthermore, water film thickness is measured, for example to decide which speed limit, and if slippery road sign, is displayed in variable message signs. The ambient weather conditions are measured with the non-intrusive sensors overhead or on side of the roadway. With these sensors it is possible to measure temperature, dew point, visibility, wind speed, precipitation and air quality. (Haug & Grosanic 2016.)

The Finnish meteorological institute is developing, together with several partners, the use of a road weather station (RWS) as part of the digital infrastructure in intelligent transportation system. The aim of the project is to improve road safety and safe passage of data between the infrastructure and vehicle. In the project an interactive road side unit (RSU) including RWS is communicating with a vehicle passing by the RSU providing weather information and alerts. And vice versa, a vehicle equipped with weather and road condition sensors can provide information for the RSU. (Safecop 2016.)

6 Traffic lights

Traditional traffic lights with time sequence control do not provide data about traffic. Today, most of the traffic lights are equipped with many sensors, usually with the inductive loop detectors, as mentioned in previous chapters. Those kinds of traffic lights can provide information about the traffic by detecting the presence of a vehicle, measuring the headway of vehicles and counting vehicles. (Lawrence & Page 2020.)

The traffic lights are getting smarter as technology evolves. Even today they are capable of communicating with the new cars. With a new control unit system it is possible to control the traffic flows in intersections efficiently. The system is open interface based and enables traffic lights to be controlled by third parties. (Liikennevalot ja älykäs liikenne 2020.)

The traffic lights can be controlled by a wireless sensor network (WSN) with a real time data gathered from various sensors. There are many ways of using the data from on road or on board sensors. For example, an adaptive traffic light algorithm can determine the sequence and length of lights based on the real time traffic detected. (Kafi, Challal, Djenouri, Bouabdallah, Khelladi & Badache 2011.) Another use of the data is an artificial intelligence (AI) controlled traffic lights which can schedule the lights based on a huge amount of data collected from surrounding sensors and previous intersections sensors.

7 GPS

The Global positioning system (GPS) is a satellite based navigation system. The satellites do not store any data they only send signals. GPS devices provide exact location, time and speed of an object. Some of the data is stored in the GPS device and all the data is collected and stored by the manufacturer of the device. The device can be any gadget with a GPS such as an integrated car GPS, separate navigation device or mobile phone. The manufacturer processes and analyses billions of anonymous data points gathered from millions devices all over the world. Therefore, the manufacturer is able to provide historical and real time data for third party. Thus, the GPS data can be used for improving for example traffic management, logistics fleet management, road safety and public transportation planning. Tracking consignments is an important solution of GPS for logistics. (HERE traffic 2021.)

A public transportation is using GPS to track buses and trams. The public transportation operators benefit the system by keeping the fleet on time more accurately. The GPS data is used to provide arrival information on the displays in stops. The advantage of using the GPS is to provide real time information to travellers. The vehicle´s location can be seen on map via smart phone application or internet browser. The application shows the time when for example a bus will arrive to the stop chosen by user and it is possible to follow the progress of the trip. Thus provides better customer service. (Thomas 2019.)

An important solution of the use of GPS is smart phone mobility as a service (MaaS) applications which are based on the location and route information of the traveller and transportation vehicles. The MaaS is a concept that combines public transportation and other service providers, such as trains, taxis and city bikes, under one service making the use of public transportation as easy and comfortable as possible for the consumer. A good example of such an application is Finnish whim app. The whim is an open concept in a way that any mobility service provider can join it and thus get valuable data for the service. The whim is collecting data about how people move, kilometres, directions, transportation modes used and geographical locations. (Hietanen 2020.)

Another good example where the GPS navigation is used is an application that calculates the time to traffic light turning green based on a vehicle speed and traffic light sequence. The application shows countdown in a vehicle integrated GPS, GPS device or smart phone. Thus, it is encouraging drivers to slow down for to arrive the intersection with green lights on. (Allen 2019.)

8 Smart phones

Smart phones have many sensors which can be used for collecting traffic data. An accelerometer measures acceleration, vibration and tilt of the phone. Also the gyroscope detects direction movements. But, it is more precise than the accelerometer and provides information about rotation and how much the phone is for example tilted. (Priyadarshini 2018.) The GPS provides information about a location, speed and altitude. By analysing the data collected from those sensors it is possible to determine the condition of the road such as bumps and holes can be detected. (Sapan 2016, 41, 44).

The mobile phones are also tracked by service providers. They are collecting anonymous data about a mobility of mobile phones thus obtaining information about people´s travels. This is done in the mobile phone network by the base stations where the phone is linked. The data collected by the operators is shared with traffic managing authorities, stored in their server and analysed. The data is used for example for infrastructure planning, traffic management, road maintenance planning, public transportation planning and the years 2020-2021 COVID-19 spreading analysis. (Salonen, Teittinen, Niittylä & Varjola 2017.)

Smartphone applications are a good source of large amount of data. Through the applications it is possible to collect many kinds of data and make complex analyses. The data is stored in cloud by the application provider for further analysis. By using algorithms to analyse the data it is possible to develop services in many ways. The data collected and saved by various different companies and application providers is often shared with third parties. Especially companies share the data with authorities, cooperation companies and operators beneficial for their business. End users and customers are provided only data in could probably be useful basis. The data is used by the companies, application providers and researchers for development and enhancing operations and for marketing purposes. (Ram, Wisniewska, Kao, Rininsland & Nevitt 2018.)

An example of improving a public transportation service with the data collected from a specially developed application is a project of the Finnish transportation infrastructure agency (FTIA). The purpose of the project was to examine how reliably by refining positioning and acceleration data produced by a mobile phone can be used for deducting the mode of transportation and mobility of people. And, can the collected data be used for to support the activities of the FTIA. The amount of analyses and conclusions made from the data is huge and the possibilities of the utilization are diverse, limited only by the tools and methods available. A reliable, high quality and comprehensive data can be used for analysing the occupancy, load and the need of modification of the traffic network. A demand for different kinds of traffic services can also be analysed. The data is saved in real time to a database in FTIA´s server for further analysis and for the possibility to share the data to third parties. (Niittylä & Varjola 2017.)

9 Vehicles

Vehicles are becoming more and more a part of the digital roadway infrastructure. They are equipped with hundreds of sensors such as cameras, infrared cameras, lidar, radar and ultrasonic as illustrated in Figure 11. Those sensors are constantly checking the surroundings. Other sensors are monitoring the functions of the parts and the performance of the car. All of the data is stored in the hard drive of the car. Some or all of the data is transferred to the car manufacturer via internet connection. (Els 2017.)

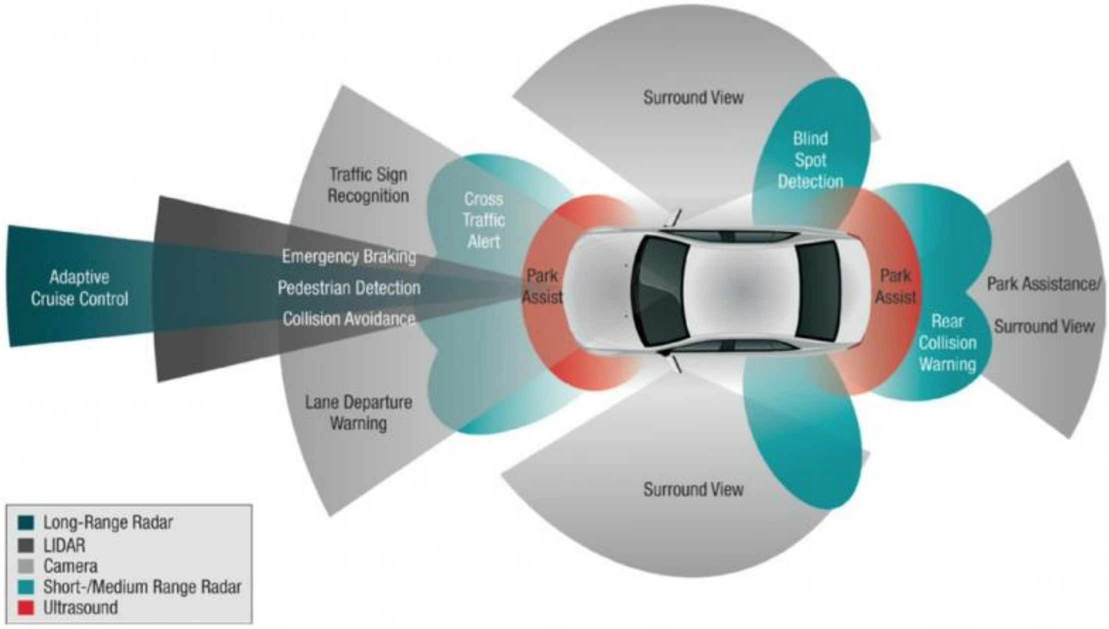

Figure 11. Smart car sensors (adapted from Els 2017)

The data is used for many purposes. The car manufacturers use the data for developing the cars and services. They can also share the data for third parties such as insurance companies, authorities and traffic management centres (TMC). For the TMCs such data means more precise picture what is going on in the traffic, to be able to respond accidents and congestion faster and better traffic flow management. Also sharing the information for the road users becomes more accurate and up to date with a real time data collected from vehicles. The economical benefits are substantial due to less need for the traditional sensors and their maintenance. With the data city planners are able to make data based decisions and investments for planning the infrastructure. (Asiag 2021)

9.1 Floating car data

Traffic monitoring with a floating car data (FCD) is positioning based method for collecting data from the road network. In this system a vehicle is acting as a sensor transferring location data through a GPS device on board the vehicle. Although as well the data can be gathered from mobile phones inside the vehicle. Mostly the data is available from public and commercial vehicles. Private cars FCD can also be collected but there is always the question for privacy issues and the willingness to share the data, in addition the amount of GPS devices continuously in use is still quite low. (Leduc 2008.)

The data acquired can be real time or historical. And, it is more accurate and more widely collected along the road network than the data from the traditional fixed station sensors. The type of data collected is such as location, speed, time and direction of travel. The data can be used for estimating travel times thus informing arrival times in variable message signs. Detecting and preventing congestions is used for better traffic flow and safety. Together with the data provided by the traditional sensors the FCD can improve the quality of the data gathered from the traffic and thus add value for the services. (Leduc 2008.)

9.2 Cooperative intelligent transportation system (C-ITS)

As mentioned before vehicles are becoming more and more part of the infrastructure and even making their own ecosystem as they are able to interact. There are three ways of defining how vehicles cooperate, in other words, share the data gathered from the sensors of the vehicle. A vehicle to vehicle (V2V) communication is a way to inform other vehicles nearby about the behaviour of one's own vehicle. A vehicle to infrastructure (V2I) is communication between the vehicle and roadside infrastructure such as traffic lights. A vehicle to person (V2P) communication exchanges information between the vehicles and pedestrians, cyclists etc. A vehicle to everything (V2X) includes all the previous forms of communication between the infrastructure, roadside units, pedestrians and other vehicles. (Car 2 Car Communication Consortium.) All that generates huge amounts of data to a complex network of data storage units and the utilization possibilities are endless.

Nordicway project is a good example of such C-ITS system. The project involves the four Nordic countries (Finland, Sweden, Norway and Denmark). Aim of the project is to demonstrate interoperability of C-ITS and to prove probe data collection functionality and feasibility (Scholliers 2016, 7). Scholliers (2016, 9) writes on the report that the key element of the Nordicway concept is the interchange server which acts as a broker server directing the messages between different actors. The Figure 12 shows the sharing and storing of data between actors in the system. The end users are all the time in connection to service provider by on board units or smart phones. Vehicles report events based on sensor values or drivers report an event by smart phone. The data of the reported event is processed in the cloud service of the service provider. Then the data is sent to the cloud of the local traffic management centre through the interchange server as illustrated in Figure 12 (ibid., 9.)

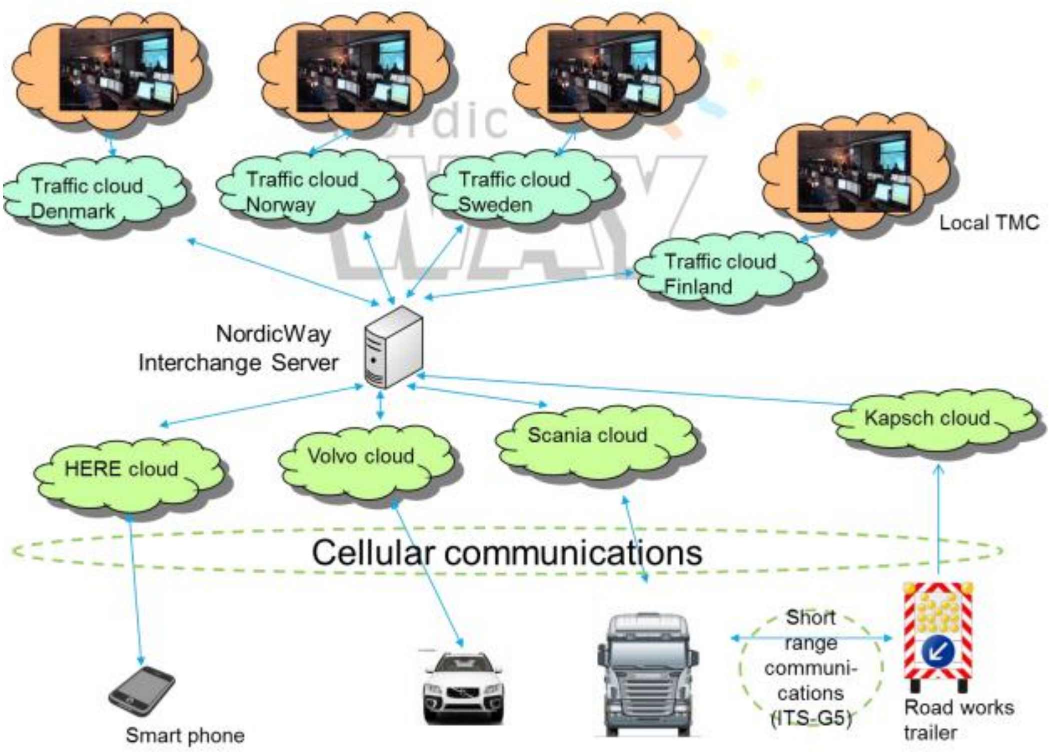

Figure 12. Overview of the Nordicway system (adapted from Scholliers 2016)

The main benefit of the system is increased safety of the road users. The system utilizes the collection of sensor data of the vehicles and reports from smart phone users. The Nordicway concept provides information about hazardous situations and severe road conditions as a C-ITS service for road users. (Scholliers 2016.)

10 Summary

The thesis seeks to create an overview of digital roadway infrastructure. More precisely the purpose is to answer the research questions set for the study. The questions are:

1. From where the data can be collected?
2. Where the data is stored?
3. How the data can be utilized?

For the first question many types of single detectors and sensors were found and introduced. The roadway detectors were divided into two different sections, intrusive and non-intrusive by their functions and installing methods. A set of sensors was introduced in form of traffic lights and weigh in motion systems. GPS, mobile phones and vehicles were introduced at their own sections.

For the second question it was found that most of the traffic data is stored and managed by traffic management authorities. The data is collected by the manufacturer from GPS devices and cars. From mobile phones the data is collected by the application and phone subscription providers.

For the third question several point of views were found. Besides the traffic authorities more and more the data is utilized by various companies from different industries and application providers. Very much of the data is utilized for marketing purposes. But luckily also still for developing the intelligent transportation systems.

According to the material the detectors and sensors have been introduced comprehensively. The governing, managing, analyzing and utilization of the data is complex and large area to handle. That part of the study remains just a scratch of the surface. I think the thesis covers quite well the topic as an overview but more detailed information is available.

In the field of ITS the very same sensors as introduced in this paper are used to create more and more intelligent, safe and sustainable traffic systems. ITS and a huge amount of companies from different fields depend on the data collected from the sensors. As the ways of data utilization found in this paper, the whole world is using the information the way most suitable for them and the different actors in the market.

The thesis depicts current state of the digital infrastructure of roadways and a little bit of what can be expected in the future. The results do not create new theories in the field of ITS because that is not the nature of the study. The results show that the same types of sensors and systems are used all over the world. Variations of those are developed all the time but the sensors and devices, from where the data is collected, are the same in the roadway infrastructure. Finland is in many ways a forerunner in developing ITS but when the systems are proven good the rest of the world will follow.

The method chosen for the study is systematic literature review which is research about researches. The results found indicate that the method was right for the study. The answers for the research questions were found, probably not all the answers but main points at least. The internet provides newest information and lots of studies to be compared and similar information was found for to consolidate the view of the subject. Many different types of sources were used and compared to the research questions. All the material used is written by experts in the field of ITS. The conclusion can be made that the information is reliable. The same information can be found by anyone with a little bit of searching and even from different sources used in this study.

As a conclusion the traditional embedded sensors are diminishing all the time because new solutions with a less need of maintenance are invented. More and more private devices are connected to the ITS and the data is collected from them.

Also the data is becoming more important due to the need of efficiency and knowledge based decision making. Therefore the accessibility to data is becoming more important. As the intelligent infrastructures and systems are developed the amount of open interfaces for data sharing is increasing. Intelligent transportation system is fascinating field to be studied more for example in the aspect of future.

More detailed information is available and by interviewing experts from different fields of professions and industries about storing and utilizing the data would have given better and more comprehensive view for those questions. Managing, governing and utilizing the data needs further research.

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