LAB University of Applied Sciences

Autonomous public area maintenance machines and best practices of them globally

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Abstract

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Title of the thesis

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Abstract

Autonomous vehicles and Artificial Intelligence became hot topics nowadays, and the future where they are fully integrated is no longer a fantasy. Although this thesis work includes information about self-driving cars, it represents autonomous machines for public area maintenance.

The commissioner of this thesis is the Public Works Department of the City of Espoo. The purpose of the study is to analyse the ways to improve maintenance work through the usage of autonomous machines. A brief history of self-driving cars and some essential technologies are provided to introduce the city representatives to the basics of autonomous vehicles to participate in Espoo's future pilots with extended knowledge. Furthermore, the best practices worldwide are given to find out what level of autonomy exists nowadays and what to learn from their experience.

As the result, this paper represents the reasons for implementation and possible challenges. The following reasons were divided into three main categories – ecological, economical and safety. Moreover, a survey is provided to show the young people's opinion about the road maintenance autonomous machines.

To summarise, autonomous machines are useful due to the lack of manpower and their 24/7 working hours. They will be especially beneficial in the parking spaces, universities, parks, and sidewalks, where the integration with other moving obstacles is minimal. However, in order for them to be operated on the main streets, a safety driver is required.

One of the main problems of the industry is a lack of united legislation and regulations. Many countries all around the world are trying to solve it by moving towards the innovative future with trial pilots of autonomous machines, and Finland is no exception.

Keywords

Autonomous, public area maintenance, self-driving

Contents

List of abbreviations

AI – Artificial Intelligence

AV – Autonomous Vehicle

AESV – Autonomous Environmental Service Vehicles

DoT – Department of Transportation

DDT – Dynamic Driving Tasks

DAS – Driving Automation System

ODD – Operational Design Domain

GIS – Geographic Information Science

SAE – Society of Automotive Engineers

CAVs – Connected and Autonomous Vehicles

SLAM – Simultaneous Localization and Mapping

1 Introduction

1.1 About the commissioner

The commissioner of this thesis is the City of Espoo, Public Works Department. Espoo is the second largest city in Finland with a population of almost three hundred thousand, and it is located in the Uusimaa region with the capital Helsinki right next to it. The special thing about Espoo is an urban structure that relies on 5 different centres – Leppävaara, Matinkylä, Tapiola, Espoon keskus and Espoonlahti. The highest decision-making authority is a Council with 75 members. It is responsible for the city's economy and operations. The Council appoints the City Board with 12 committees that represents the city, which is responsible for finances and the practical management of municipal administration (Figure 1). The Public Works Department is a part of the Technical Services. (Espoo 2021.)

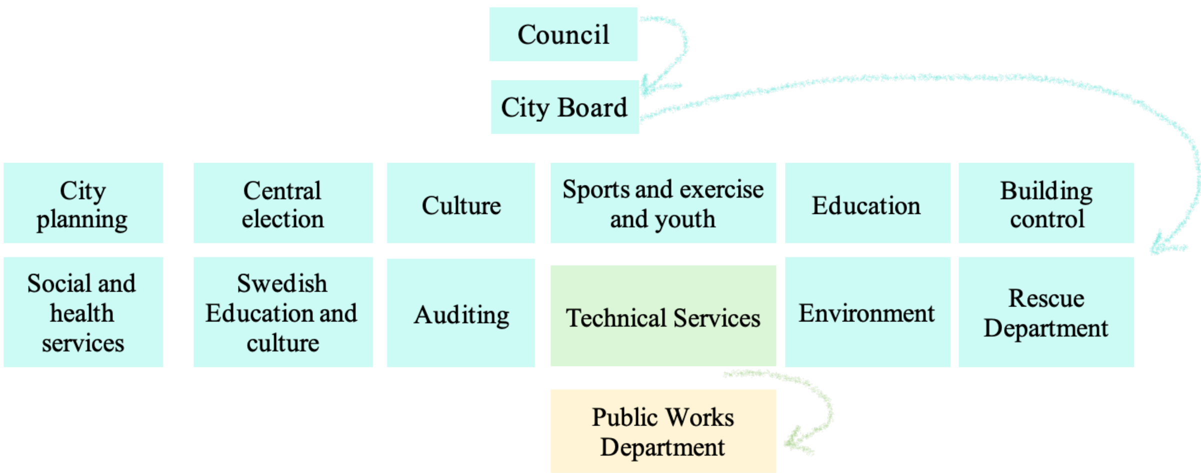

Figure 1. Espoo's decision-making authorities

Kake (Kaupunkitekniikan keskus), in other words the Public Works Department, is responsible for constructing, planning and maintaining public areas. Moreover, they play a part in improvement of the city environment by making sure it is safe, functional and accessible (Espoo Public Works Department 2020, 3). Maintenance work includes repairing road surfaces, binding dust on gravel roads, levelling road surfaces, and managing drains. In winter, it is necessary to clear snow from roads and prevent slipperiness by sweeping the roads (Espoo Public Works Department 2020, 10).

1.2 Topic background and motivation

Espoo is the city of innovation and development. Like many other cities in Finland, Espoo is going towards a carbon-neutral city by 2030. It is also taking a part in the Helsinki Metropolitan Area Climate Strategy 2035. Many steps have to be completed before achieving that goal.

Firstly, Espoo needs to improve its public transport and encourage people to use it more often, as well as to create a well-functioning cycling city. For that reason, good infrastructure should be provided, and bike paths have to be cleaned in winter to provide comfortable and safe riding. The number of people cycling in the summertime is not a problem, although in winter the usage of bicycles decreases noticeably. One solution was to use the self-driving snow plough. For that reason, the City of Espoo has planned a pilot with an Estonian startup company named Lumebot to try their autonomous snow removals covering 6 km of the pedestrian way, including bicycle paths. That was one of the main topic's backgrounds to do the global research and contribute to the upcoming pilot with extended knowledge.

Another significant reason is the difficulty of finding new working labour. Due to the fact that our generation Z was firstly described as the "digital natives", we integrate our lives with the internet and going towards innovations. That brings new kinds of jobs but at the same time, reduces traditional ones like truck drivers. Therefore, autonomous machines would offer a suitable solution.

It is a known fact that Covid-19 affected many industries, which includes the city maintenance work. It reduced working labour, as well as decreased the psychological public trust towards the manned cleaning. This topic will be discussed further as one of the main advantages of using unmanned machines.

1.3 Purpose and objectives of the research

We live in a new era of technology and innovation. The desire to simplify our lives drives progress. It is only a matter of time when AI will be a part of our everyday lives and robots will surround us everywhere. Therefore, we as a society need to understand why it is beneficial to use autonomous solutions and equipment to improve our routine work. The purpose of this thesis is to analyse the ways to improve the maintenance work of the Espoo Public Works Department through the implementation of autonomous machines. A brief history of autonomous cars and essential technologies provided to introduce the reader with the basic knowledge to understand how all the autonomous machinery works, including the ones used for public area maintenance. Moreover, the best practices worldwide are provided to find out what level of autonomy exists nowadays and how to learn from their experience. Finally, as the result, this thesis will represent the reasons for implementation and possible challenges.

1.4 Research methodology

In this study, quantitative and qualitative study methods have been used, such as interviews, webinars and a survey. Moreover, the data was provided by the city of Espoo and private companies. Despite this, the main research method was a literature review, including books, articles, and master thesis works. One of the interviews used in this work was directly completed by the author, and the other ones were internet-based video interviews.

Autonomous driving technology is rapidly developing, and that is why a significant amount of new data accumulates day by day. The data provided in this thesis work represents the current situation of the field.

2 Autonomous vehicles

2.1 History

When we think of autonomous cars, we inadvertently think about something futuristic that has appeared quite recently. In fact, the first mentions of self-driving cars date back to the early 20th century.

As everything in the world has its history, the autonomous vehicles have its own, and we need to understand that public area maintenance machines are the same driving cars but only with specific functions.

It might have started during the summer of 1939 at Futurama Exhibit in New York when General Motors with famed designer Norman Bel Geddes absolutely surprised its public with the possible future image in 20 years (Figure 2). Viewed by 5 million people, Futurama encourages the idea of self-driving cars and high-speed roads. A lot of people are not able to find a solution to a problem before the way is shown to them. (Bel Geddes 1940.)

Figure 2. Street Intersection. City of Tomorrow (Bel Geddes 1940)

Throughout the time, other countries were coming closer to fully autonomous vehicles. In 1977, the Japanese Tsukuba Mechanical Engineering Lab made the world's first truly driverless car. The car could drive around but only at a speed of about 32 km/h. Without a doubt, the technology of autonomous vehicles started to become more advanced. In the 1990s a German engineer and his team created a fully autonomous vehicle that could reach 97 km/h (Figure 3). (Gringer 2020.)

It was the VaMP, a 500 SEL Mercedes re-engineered with the computer that based on real-time evaluation of image sequences controlled a steering wheel, brakes and throttle. The software translated sensory data into necessary driving commands. Because of the limited computing power of those times, appropriate computer vision strategies were required to react in real time. Dickmann's team solved it with an innovative approach to dynamic computer vision. The VaMP did not use GPS, therefore, only drove based on its vision. Attention control, including the movement of the camera platform, allowed the system to focus on the most important details of visual input. For this, four cameras with two different focal lengths for each hemisphere were used in parallel. Kalman filters have been extended to handle perspective images and provide reliable autonomous driving even when it was noisy, and the uncertainty was present. 60 transputers and a type of parallel computer were used to meet the enormous computational requirements of the 90's standards. (Dickmanns 2007.)

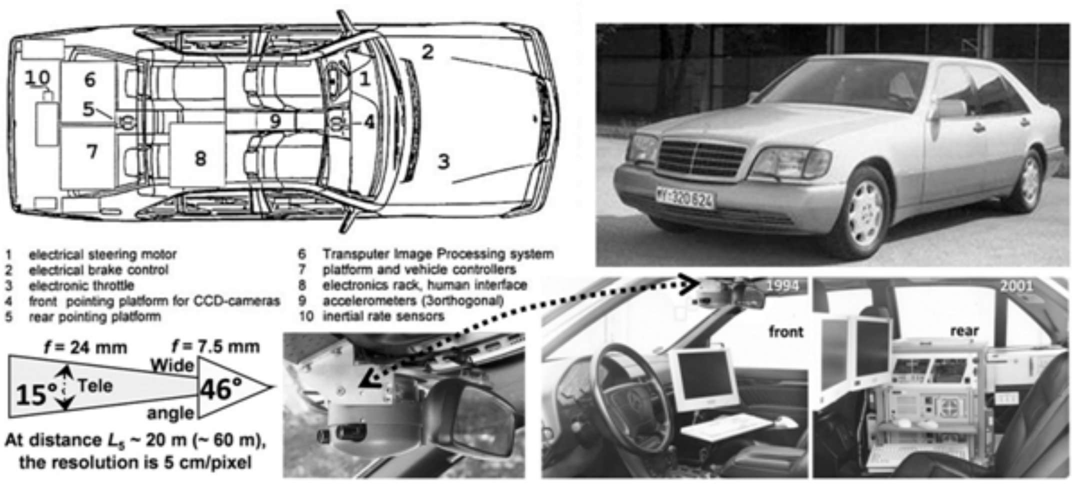

Figure 3. VaMP driverless car (Dickmanns 2007)

Figure 3 presents components and the view into the passenger cabin of the VaMP driverless car that was constructed by the team of Ernst Dickmanns and Mercedes-Benz in the 1990s. (Dickmanns 2007.)

Without a doubt, from the beginning of the 21century, a lot of car manufacturers started their process of testing driverless car systems, such as Waymo, Google, Tesla, Uber and even Apple that is planning to launch their fully autonomous iCar in 2024.

Nowadays, we do not only talk about autonomous cars. The autonomy came not only to transportation but to many other industries like logistics, forestry, farming, production, construction, and of course, public area maintenance.

2.2 Levels of automation

SAE International (The Society of Automotive Engineers) presented a new chart with its “Levels of Driving Automation” standard. The chart defines six levels of driving automation starting from no automation to full automation. The U.S. Department of Transportation (DoT) in its “Federal Automated Vehicles Policy” uses J3016 standard with six levels of automation for on-road motor vehicles. Furthermore, the document became a global standard that was adopted by other parties in Autonomous Vehicles technology (Figure 4). (Shuttleworth 2019.)

Below the precise description of levels is presented with a help of the standard J3016, 2016 provided by SAE International:

Level 0 (No driving automation)

The driver must constantly supervise and perform the whole DDT (Dynamic Driving Tasks). The majority of our cars are manually controlled vehicles level 0. Although some of the cars may have a warning or support system like momentary emergency intervention, the Driving Automation System (DAS) does not perform any part of the DDT on a sustained basis.

Level 1 (Driver Assistance)

Driving Automation System performs either the longitudinal or the lateral vehicle motion control subtask and turns off immediately if the driver requests. The driver decides when the usage of DAS is appropriate and whether it is not and performs DDT whenever it is required or desired. One of the examples could be the park assist, where a driver must control the speed, but the car controls the steering. Many vehicles nowadays can offer you Level 1 automation.

Level 2 (Partial Driving Automation)

The main difference between level 1 and level 2 is that DAS performs part of the DDT by executing both the lateral and the longitudinal vehicle motion control subtasks. However, the driver is still required to have his hands on the wheel all the time and control the environment. Tesla Autopilot, Audi Traffic Jam Assist could be one of the examples of the Level 2.

Level 3 (Conditional Driving Automation)

Level 3 has appeared to our present days just recently, there is a huge technological gap between Level 2 and Level 3. At this level, DAS performs the complete DDT, but not DDT fallback (J3016 2018). DDT fallback is responsible for achieving minimal risk conditions after the ADS failure. Therefore, the driver must be ready to take control of the wheel when it is needed. Almost all Tesla models built after 2016 has Level 3 automation, they have HD-cameras and highly advanced Artificial Intelligence-powered image processing. Though, not only Tesla is capable of those features, car manufacturers like Audi, BMW, Porsche, Toyota, and Honda are purchasing third-level systems.

Level 4 (High Driving Automation)

That is what I would call a fully autonomous car, at Level 4 the car has control over both DDT and DDT fallback. This means that driver is not required to control the wheel, however, only within a limited ODD (Operational Design Domain), e.g. geofenced areas, highways, etc.

Level 5 (Fully Driving Automation)

Finally, Level 5 is the level where DAS is taking control over everything, including DDT and DDT fallback in any circumstances and environments. That is the one car that people imagine when they think about the future, where they are only performing as passengers and do not need to drive at all.

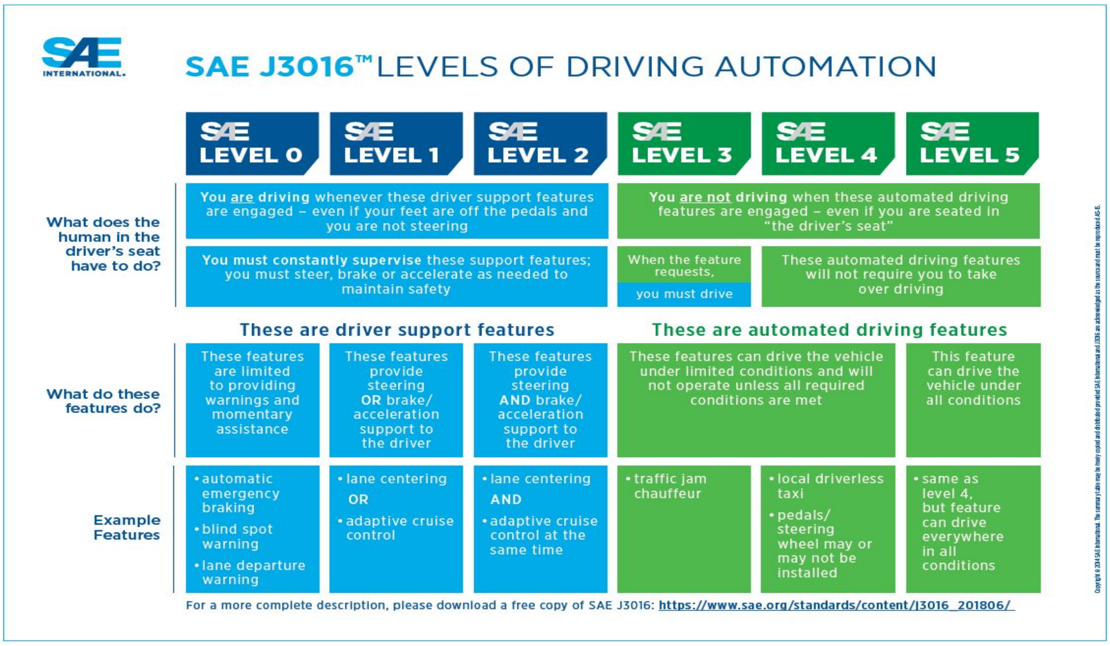

Figure 4. SAE J3016 Levels of driving automation (Shuttleworth 2019)

In Figure 4, the 6 levels of automation chart presented by the Society of Automotive Engineers (SAE). The new chart offers more "consumer-friendly" definitions and terms (Shuttleworth 2019).

2.3 Technology and equipment

There is no doubt that a vehicle needs advanced technology and equipment to succeed at any level of autonomy. Self-driving cars include a significant amount of technology in them. As humans need their organs of sense, autonomous machines need their type of eyes and ears. That is what sensors are made for, and each of them has its purpose – to see the obstacles, to detect their location, to measure their size and form, etc (Figure 5). Moreover, a vehicle needs its brain, Artificial Intelligence, and a suitable environment with the ability to find itself around this environment. In this case, the machine needs suitable software that calculates probabilities and makes a decision based on the data provided by sensors.

2.3.1 Sensors

Nowadays car manufacturers use 4 main types of sensors – camera, radar, ultrasound, and LiDAR. Together they generate wide data for the car to understand the environment surrounding it. After all, to replace humans from the wheel, cars have to be better in everything, safer and smarter.

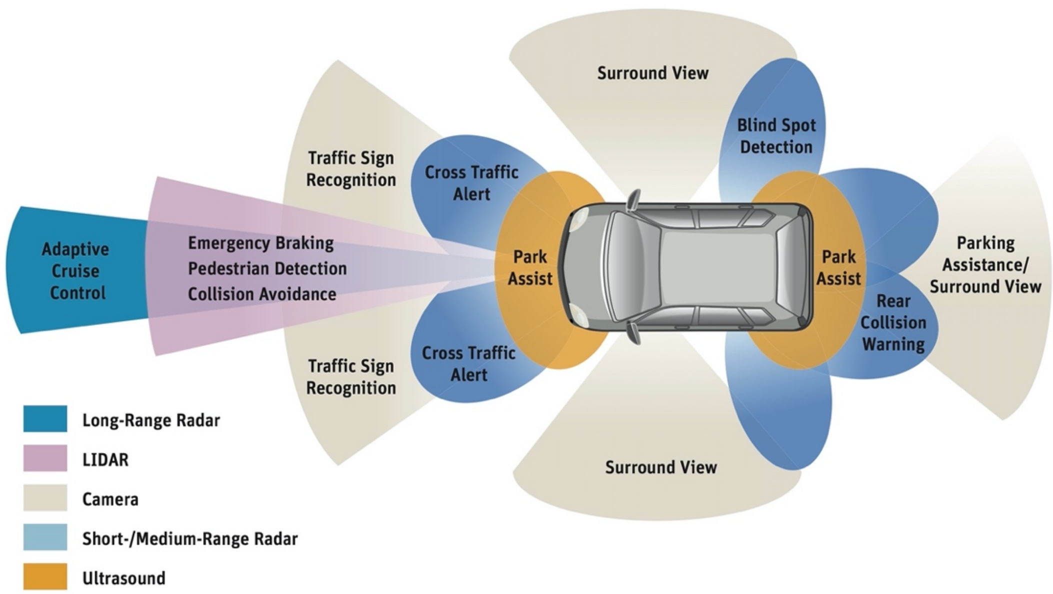

Figure 5. View of the sensors (Ansys 2018)

Figure 5 illustrates the fields of view of the sensors (Radars, LiDAR, Ultrasound, and Camera) which are responsible for various functions. For instance, the Camera is responsible for surrounding view, traffic sign recognition and parking assistance. Long-range Radar performs adaptive cruise control. LIDAR takes over emergency braking, pedestrian detection and collision avoidance. Ultrasound is there to help with park assistance. Finally, a short or medium-range Radar is needed to watch the corners of the vehicle, perform blind-spot detection, cross-traffic alert and rear collision warning. (Ansys 2018).

Cameras

Bosch management board member Harald Kroeger specified that they want to make cars better drivers than people to increase road safety (Bosch Media Service 2019). Our eyes may be wonders of nature, but they also have their weaknesses when it comes to visual perception. Only because we see something does not necessarily mean that we recognize or understand it. A lot of drivers who end up in accidents say that they had been looking in the right direction but failed to look at something else. It is estimated that up to 50% of the road traffic collisions refer to this phenomenon. The camera is better than the human eye in this respect, not only because it never gets tired but also because it works after hours of driving as it is its first kilometre (Figure 6). On the other hand, cameras have their weak side when it comes to bad weather conditions like fog, rain, etc. (Bosch Media Service 2019.)

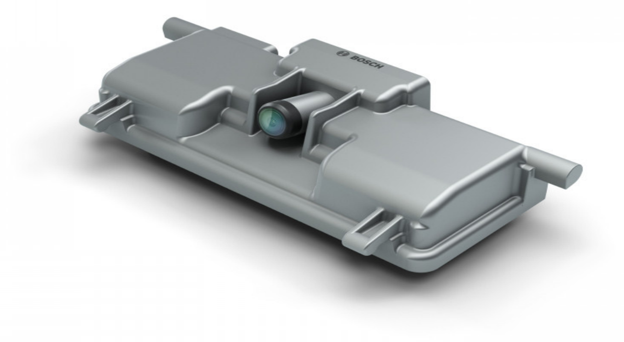

Figure 6. Bosch camera with AI (Bosch Media Service 2019)

Figure 6 represents the new Bosch camera with AI for driver assistance and automated driving. The advantage of that camera is in its strong object recognition, enabled by Bosch's multi-path approach. The camera solves multiple tasks like road signs and pedestrian's recognition, reads text and numbers on the signs and shows that on the monitor of the driver. The camera's intelligence is integrated into a chip, known as V3H, which was made by the Japanese company Renesas. Furthermore, it can improve legacy driver assistance systems and expand their range of application. (Bosch Media Service 2019).

Radars

Radar (Radio detection and ranging) with simple words is a sensor that uses radio waves to detect objects by receiving back the echo. Radar sensors provide important information for safe and reliable autonomous vehicle operations. There are 3 major classes of radar systems that are typically used in automotive active safety systems: Short-range radar (SRR) used for collision proximity warning and to help with limited parking assist features; Medium-range radar (MRR) to perform blind spot detection and to watch the corners of the vehicle; Long-range radar (LRR) for adaptive cruise control (ACC) and early collision detection functions. Today's radars integrate technology that 20 years ago could only be found in advanced research in defence laboratories and aerospace. (Carpenter 2018).

The MRR uses the frequency band of 76–77 GHz and it is a bi-static multimodal radar with 4 independents receive channels and digital beam forming (DBF) (Figure 7). These technologies allow the medium-range radar to be tuned with independent antennas for different directions, which makes it possible to settle the radar's field of view depending on the situation. The system is capable of reacting to vehicles in front up to 160 metres. With a help of the tilting antenna, the system gives a wide angle of coverage at closer ranges, thus, a pedestrian passing from behind the car is detected at an early stage. (Bosch Mobility Solutions 2015.)

Figure 7. Bosch medium-range radars (Bosch Mobility Solutions 2015)

In Figure 7 the mid-range radar sensor for the front application (MRR front) under the number 1, and the mid-range radar sensor for rear applications (MRR rear) under the number 2 are presented.

LiDAR

LiDAR sensing is shortly a remote sensing technology that emits laser light beam with defined intensity and measures the reflected beam arrival time detected by the photodiodes (PD) within the sensor. This data shows the horizontal or angular distance to the object. In this way, LiDAR is similar to Radar, except that it is based on discrete pulses of laser light. LiDAR is considered as an active system due to its light emission and detection arrangement which enables the sensor to be used in both clear and harsh environments. The basic setup of a LiDAR consists of a transmitter and a receiver. Narrow width light pulses in the range of several hundred nanoseconds are generated by the laser. A beam expander can be included in the system in the transmitter unit to reduce the divergence of the light beam before it is sent out to the atmosphere. At the receiver end, a geometrical optical arrangement collects the backscattered photons in the atmosphere. Usually, it is followed by an optical analysing system which is selected depending on the application-specific wavelength or polarization states out of the collected light. The chosen optical wave-length radiation is received at the detector where the optical signal is converted back into an electrical signal. The distance of the object is calculated by the electronic time calculation with computer-stored data. Most LiDARs have a single laser emitter or detector pair combined with a moving mirror to effect scanning across at least one plane (Figure 8).

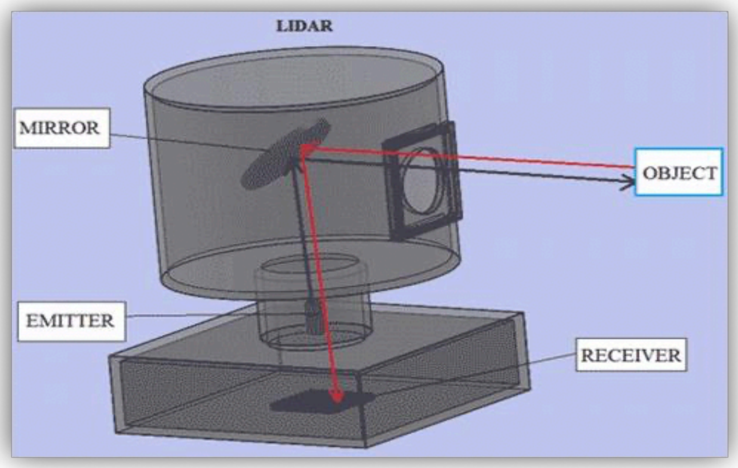

Figure 8. Basic parts of LiDAR (Bhuiyan 2017)

The 3D construction setup of the available LiDAR sensor is shown in Figure 8. The mirror reflects the emitted light from the diode and reflects the return light to the detector. The usage of a rotating mirror in this application is for achieving 90-180 degrees of azimuth view. The resulting product of the LiDAR is a spaced network of highly accurate elevation points, also called a point cloud, which can be used to generate three-dimensional representations of our planet's surface and its features. Wavelengths used in LiDAR depend on the application and varies from about 250 nanometres to 11 micrometres. (Bhuiyan 2017).

IMU Sensors

An IMU is a type of sensor that measures angular rate, force and a magnetic field. IMUs are made up of a 3-axis accelerometer and a 3-axis gyroscope, which would be considered a 6-axis IMU. The specific thing about IMU sensors is that they have an environmental independence, which means they do not need to know about the external world. Technically, the term "IMU" refers to just the sensor, but they are also consisting of sensor fusion software that combines data from multiple sensors and provides measures of orientation. (Teschler 2018).

GPS

The Global Positioning System (GPS) is a radio navigation system based on satellites. The whole concept is based on the time and the known position of GPS-specialized satellites. Each satellite continuously transmits a radio signal that contains current time and data about its position. The time delay between the satellite's transmitted signal and the receiver's received time is proportional to the distance from the satellite to the receiver, as the speed of radio waves is constant and independent of the satellite speed. (GPS 2021.)

2.3.2 Artificial Intelligence

Artificial Intelligence models human perception and decision-making processes by using deep learning and guides actions in Driver Control Systems such as steering and brakes (Lutkevich 2019). A lot of training must be initially undertaken for the AI, so the vehicle could know how to react in different situations. Sensors provide the enormous amount of data every minute. Therefore, the vehicle needs something not to only receive this information, but also understand it to provide the needed action (Micron 2021).

The self-driving vehicles consist of more lines of code than any other software platform that has been developed to our time. That requires more than 1 TB (terabytes) of storage with the continuous and uninterrupted stream of the data (Micron 2021).

Moreover, the AI enables another beneficial ability for the machines – predictive maintenance. So, the maintenance could be done when it is needed, not when it is scheduled.

That makes processes for the car manufacturers more efficient and cost-effective. (Indust Labs 2020.)

However, AI also has its challenges like real time response, security, or accuracy and reliability. The problem with verification and validation has to be an important aspect when speaking about the cyber security. Some small changes in the received data can be misread, which would cause a catastrophic result (Hristozov 2020). One example is the fatal car accident in March 2018, when a woman was hit by an Uber self-driving vehicle (BBC 2019).

2.3.3 GIS systems

Implementing self-driving vehicles will definitely require advanced geospatial technology, and GIS will have an important role. As it was described earlier, the machine needs sensors and computer-vision algorithms to operate by itself. Meanwhile, GIS is the basis for the navigation of the car, as it selects the most efficient route with a help of a route optimization tool. Well-detailed maps and routing data will be extremely beneficial in case of limited visibility. Map providing companies have already started to make 3D maps of roadways over the world (USC GIS 2019). With the precise information about the street signs and road conditions provided by the maps, the vehicle can focus more on the pedestrians, which will improve safety.

2.3.4 5G connection

5G mobile connectivity will represent a critical part of the future of autonomous vehicles and essential, if Level 5 vehicles will become a reality. That is why Orange teamed up with PSA Group in 2017 and started testing 5G network technology for connected vehicle applications. (Hello Future Orange 2019.)

5G will enable the Internet of Things (IoT) capabilities in autonomous cars. The sensors that were discussed earlier will obviously generate massive amounts of data. Handling, processing and analysing this data will need a much faster network than existing 4G technologies. Autonomous car systems require high data-processing speeds if they want to be the same as the speed of human reflexes. Moreover, 5G will enable Vehicle-to-Vehicle (V2V) and Vehicle-to-Everything (V2X) connectivity in cars, which will help make vehicles safer and more reliable. (Hello Future Orange 2019.)

2.3.5 Vehicle-to-vehicle communication

Another possible solution to improve the safety of machines is a Vehicle-to-Vehicle (V2V) communication. It is a wireless ability to exchange the information between the cars about its speed or the location within a range of approximately 300 metres. This wireless protocol is called Dedicated Short-Range Communications (DSRC). When the DSRC combines with GPS technology, we get a V2V communication as a result. It would help in avoiding crashes or a congestion of cars. Unfortunately, you can only achieve the goal if all the vehicles would communicate so. (NHTSA 2021.)

There are several benefits from using V2V communication. Firstly, with the "Emergency electronic brake light application" the driver is notified in advance, if the car ahead is breaking. Secondly, the "blind spot application" allows to virtually see what is happening in the car's blind spot. Even in the public area maintenance, there is a way for several different manufacturers to make their machines connected. They could use the data to see each other's path history or path prediction to minimize the crashes. (V2V Communication 2016.)

V2V is only a small part of the Vehicle-to-Everything communication (V2X) (Figure 9). That enables vehicles not only to communicate with each other but also with the infrastructure and environment surrounding it.

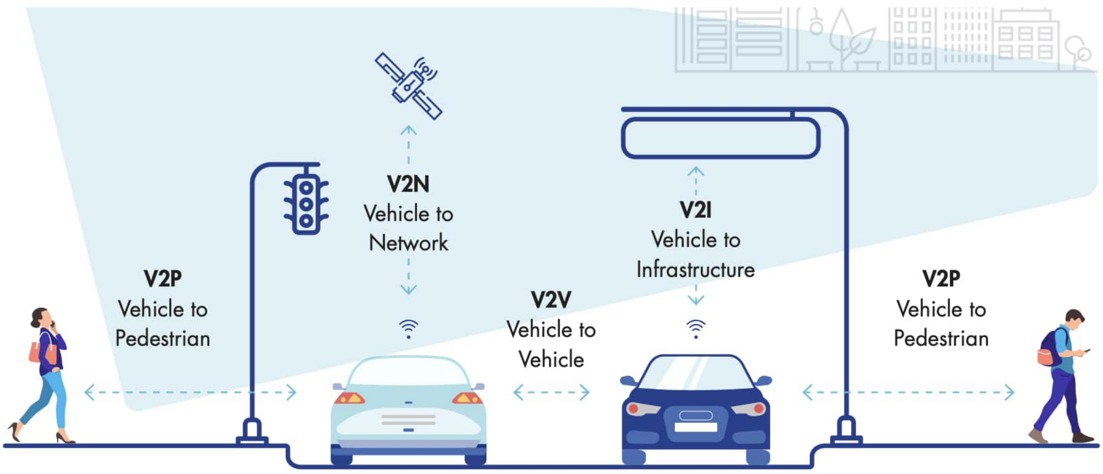

Figure 9. Vehicle-to-Everything Communication (Thales group 2021)

In a Vehicle-to-Everything Communication system, data arrives not only from the other cars but from parking spaces, traffic lights (V2I), as well as from the pedestrians' smartphones (V2P). Additionally, that technology can warn the driver about an upcoming traffic jam and suggest another efficient road. (CFI 2021.)

3 Future pilots in Espoo

3.1 Preface

The Public Works Department has planned pilot projects in the city of Espoo. One of them is a pilot with the Estonian startup company Lumebot, which had to become an important thesis topic. While it could not start in winter 2020/2021, it is nevertheless an interesting project that will hopefully take place next year. Meanwhile, a Finnish company announced its first fully autonomous street sweeper in the summer of 2020. After attending a presentation at the Helsinki Oodi Library on September 29 of 2020, both sides decided to start cooperation this coming spring. This section will describe more about the above-mentioned companies. The data was collected from the articles, interviews and from the companies themselves.

3.2 Trombia Technologies Oy

Trombia Tech is a Finnish road maintenance equipment manufacturer best known for its innovative dust and snow clearing technologies. Trombia Tech's parent company Snowek Oy was founded in Kuopio, Finland in 2011. From the very start, the company's vision was to create a new decade of modern road maintenance attachments. They started with a snow plough portfolio and became a leading snow plough brand in the Nordics countries with over 1 million USD after the first winter. (The story of Trombia 2020.)

"Everything will change" – with those words Trombia Tech launched their new world's first high power autonomous street sweeper. The company's Trombia Free cleaning device is built to be operated fully autonomous in all-weather conditions (Figure 10). Furthermore, it is the first vehicle in the global heavy equipment industry that was electrified without compromising the power and performance capabilities.

Figure 10. Trombia Free (Trombia 2020)

In Figure 10, you can see Trombia Free performing test drive in Jätkäsaari area in Helsinki.

3.2.1 Features of Trombia Free

The performance

The performance of the autonomous machines is an undoubtedly popular question of people. Trombia method was originally made for market need to develop a hydraulic attachment for construction equipment that would also remove PM2.5 dust off the streets. Trombia combines mechanical sweeping, aerodynamics inside the sweeper and a cyclone technology which they use to clean the air in the process. Trombia Free's effective dust and debris removal width is 2.2 metres with an autonomous top speed of 6 km/h (Figure 12). (Trombia Free Launch 2020.)

The power

The main challenge of the team was always the limited power available. With the power available from the hydraulics, it was simply impossible to make suction strong and fast enough. Trombia Free only uses on average 6kW in urban area cleaning, which is almost like a self-propelled grass cutter. (Trombia Free Launch 2020.)

All weather autonomous

For all the weather functionality you need to be able to filter out the noise that rain or snow brings out. This can be done with the sensors that can tolerate those conditions and also algorithms that can filter out the noise and even occlusions in the data. When you have the point-cloud based method, where you map the environment, it doesn't matter if it is outside or inside. Especially, the LiDAR-sensors that are immune for the changes in the sunlight or illumination. (Trombia Free Launch 2020.)

The noise

Trombia Free's noise level is approximately 75db when measured from 5 meters distance, which means that you can have a conversation without Trombia Free disturbing you (Figure 11). (Trombia Free Launch 2020.)

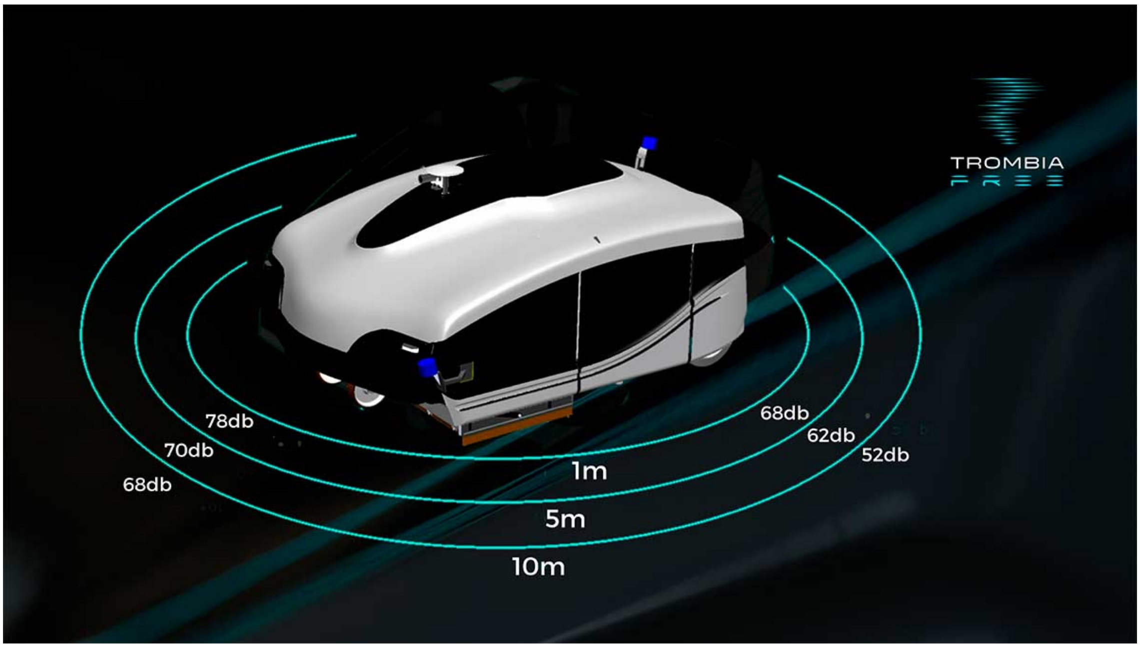

Figure 11. The noise level of Trombia Free (Trombia Free 2020)

3.2.2 Comparison between Trombia Free and other trucks

Trombia Tech has provided the comparison table between Compact Sweeper, Electric Compact Sweeper and Street Scrubber with Trombia Free (Figure 12, Figure 13).

	Compact Sweeper	Electric Compact Sweeper	Street Scrubber	Trombia Free
Dust removal power	60-70kw	7-10kw	100-150kw	6-16kw
Dust removal width	0.4-1.0m	0.4-1.0m	0.8 - 2.0m	2.20m
Full performance speed	0.5 - 1.5km/h	0.5 - 1.5km/h	1.0 - 2.0km/h	2.0 - 6.0km/h
Cleaning efficiency	200 - 1500 m2 / h	200 - 1500 m2 / h	800 - 4000 m2/h	4 400 - 13 200 m2/h

Figure 12. Comparison table (Trombia Free 2020)

As you can see from the Figure 12, the dust removal width and full performance speed is significantly higher comparing to the other options. By multiplying these two characteristics, we get the cleaning efficiency respectively.

	Compact Sweeper	Electric Compact Sweeper	Street Scrubber	Trombia Free
Total engine power	60 - 90 kw	10 - 20 kw	200-250 kw	6 - 10 kw
Cleaning efficiency	200 - 1500 m2 / h	200 - 1500 m2 / h	800 - 4000 m2/h	4 400 - 13 200 m2/h
Power requirement	40 - 450 kwh /1000m2	6,6 - 100 kwh /1000 m2	50 - 312 kwh / 1000m2	0.45 - 2,2 kwh /1000m2
High power cleaning	–	✗	✓	✓

Figure 13. Comparison table (Trombia Free 2020)

It is shown on the Figure 13 that the advantage of Trombia Free is its low power requirement, approximately 0,45-2,2 kWh of energy in 1000 m2.

3.2.3 Interview with Trombia Free engineer

Trombia Tech has provided a lot of useful information on their website and the interviews. However, some information that was not mentioned earlier was taken from the personal interview. The interviewee is Petri Heikkinen, Head of Automation and Mechanical designer at Trombia Technologies.

- Question 1: What are the specific sensors that you use except for LiDAR?

"The autonomous system uses Lidars, GPS and IMU sensors. IMU measures inertial movements such as acceleration. The machine itself measures, of course, battery voltages, motor speeds, etc."

- Question 2: What would you take as an actual sweeping & high-power dust removal speed from 2 to 6 km/h if we talk about bicycle road and would you recommend taking a single battery package or double for the municipality?

"EUnited PM2.5 standard tests are running at constant speed of 4km/h. We have unofficially achieved one of the highest scores ever recorded in that test. So, in that sense, we are able to do high power dust removal at least that speed. Normal everyday upkeep cleaning can be done with even higher speeds. Our wheel loader version can clean bicycle roads 10km/h, but at those speeds you are losing the best dust removal capability. I would say that in normal municipality upkeep cleaning the single battery pack is sufficient enough."

- Question 3: In Q&A, you mention the calculation of cost efficiency, which is 15 time higher with an estimation of all the costs. Is it possible somehow to see those approximate calculations or to know your price list compared to the other manufactures in %?

"If we look at the cleaning speed alone, we get many times higher efficiency compared to street sweeper truck. And then comes the energy needed per m2 of cleaned area. Large street sweeper trucks are also quite complex machines. Trucks have many wear parts that need to be replaced often to maintain good results. Basic measuring units are cleaned area per hour (the speed) and needed energy per area (The effiency/economy). Please note, that many street sweepers are converted from diesel to electric. The interesting thing is that at the same time motor powers are dropped to fraction. If you maintain same cleaning system, to get same cleaning result with fraction of the power is just gets impossible."

- Question 4: There still should be an operator that will control and maintain the machine, do you think a worker from Espoo could be adapted to it or it is only Trombia's job as a provider?

"Sure, current street sweeper operators are highly skilled professionals, that know how to do the job. There are basic principles that you have to understand to do the job efficiently and with good results. Most often comment about autonomous machines is "Great, there goes another job." Underneath the futuristic body there is still a street sweeper machine with nuts and bolts. Of course, current workers need to learn and adapt to new methods and systems."

3.3 Lumebot

Lumebot is a young startup company from Estonia that produces autonomous street cleaning machines. The pilot in Espoo was planned for the end of 2020, although because of the pandemic situation it has been delayed until later notice.

Lumebot uses an array of sensors for understanding the environment around it. Visual scanning and 3D mapping are done using SLAM camera and a depth camera. Additionally, perimeter cameras are used for object detection. During the night-time or in difficult weather conditions (snow, rain, etc.) they rely on sensors that do not require visibility. Using the 3D maps they can create position and locate themselves at all times. Locating the robot at all times in an urban environment without the GPS is the key to autonomous driving. The key to safety is sensing the environment around the robot. The long-range sensors can detect objects a few hundred meters away. (Lumebot 2020.)

Firstly, Lumebot is developed to remove snow (Figure 14). The machines are available 24/7, and they start to work as soon as the snows starts, which means the height of snow is always under control. (Lumebot 2020.)

Table 2 presents some of the technical characteristics of Lumebot.

Weight	**Working time**	**Charging time**	**Area per robot**
500 kg	2 hours	20 minutes	5000 m^2

Table 2. Lumebot technical characteristics

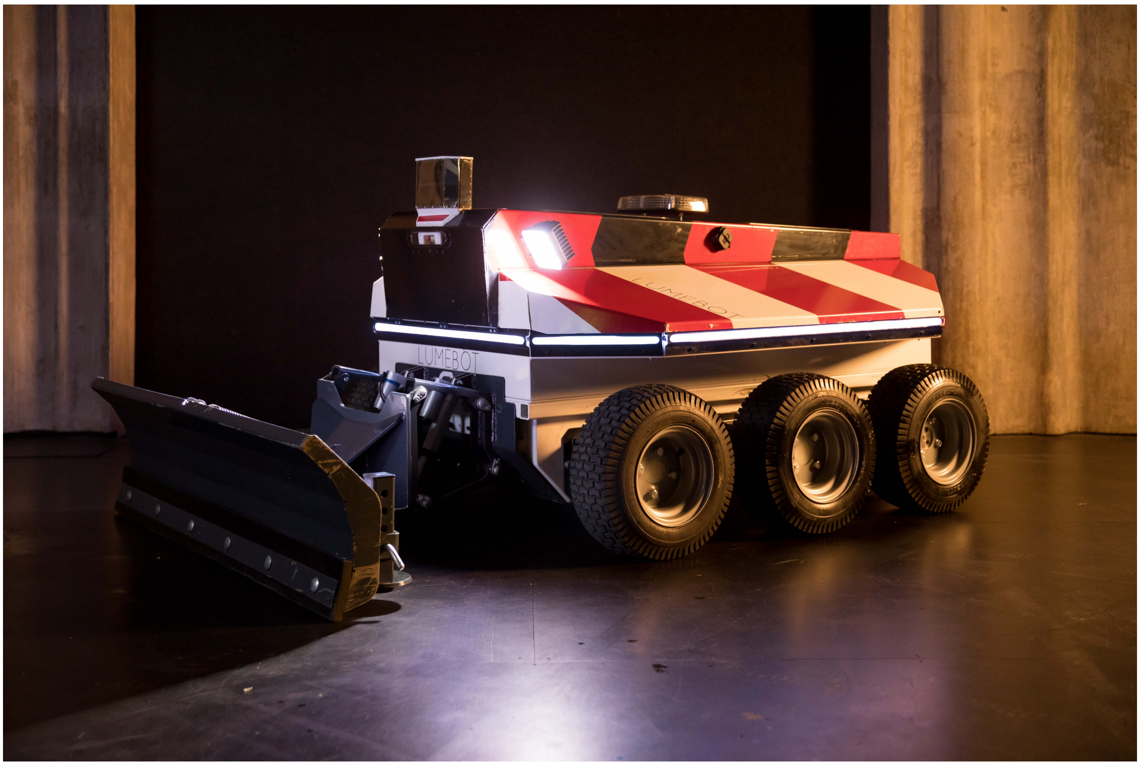

Figure 14. Lumebot snow removal (Lumebot 2020)

Lumebot is also designed to manage street sweeping (Figure 15). The robots are suitable for sidewalks, parking lots, parks, university campus and others (Lumebot 2021).

Figure 15. Lumebot street sweeper (Lumebot 2020)

3.4 Cooperation with Aalto University

Aalto Autonomous systems group has been running practical research on semi-autonomous and autonomous mobile robots, mainly in agriculture and forestry for more than 20 years (Aalto University Autonomous Systems 2020). I believe that cooperation between Aalto university and the City of Espoo would be a great opportunity for both students who are passionate about new research fields and the public works department, as they are not only responsible for the road maintenance, but for the green sector that should be taken care of as well.

During the thesis writing process, we have visited the Department of Electrical Engineering and Automation at Aalto University. The group specializes in machine perception, simultaneous localization and mapping (SLAM), navigation, path planning, and multi-robot systems related issues in dynamic environments (Figure 16) (Aalto University Autonomous Systems 2020).

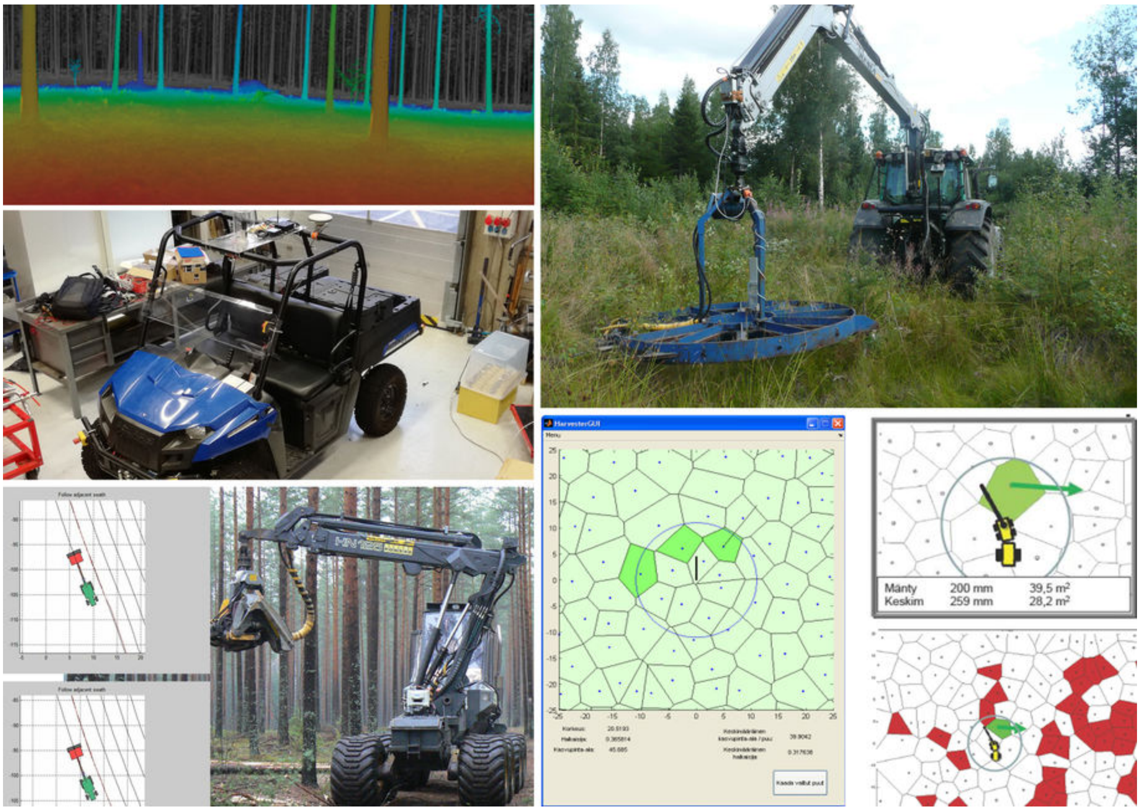

Figure 16. Projects of Autonomous Systems team (Aalto University Autonomous Systems 2020)

The Aalto team has developed a perception system for forest harvesters that is capable of forest SLAM. Automation of silvicultural machines has been studied with a help of machine vision and laser scanners for recognizing the young trees that should be left to grow, and other trees that could be cut down. The developments were studied with real machines, and ISOBUS networked control systems were implemented. Path planning, automatic navigation and path tracking with model prediction have been developed as well. (Aalto Autonomous Systems 2020.)

ISO 11783, or Tractors and machinery for agriculture and forestry – Serial control and communications data network is a communication protocol. It is commonly referred as ISOBUS, and based on the SAE J1939 protocol, which specifies a serial data network for communications on agriculture or forestry machinery. (ISO 2017).

4 Practices around the world

4.1 Idriverplus

Idriverplus, a Beijing-based company of self-driving vehicle and robotics systems, raised over 100 million yuan (14.6 million dollars) in September 2020. Idriverplus, one of the first Chinese companies that launched the commercialization of autonomous technology and began mass production. The street cleaning vehicle, called Viggo, is an autonomous purely electric solution for sweeping roads intelligently (Figure 17). While cleaning, Viggo can automatically track and avoid obstacles with reliable performance and monitor real-time vehicle information. (Idriverplus 2021)

More than a hundred units are in operation in universities, factories, amusement and general parks, city streets in Beijing, Tianjin, Shanghai, and other provinces and cities. Idriverplus also has strategic cooperation partnerships in Singapore, Dubai, Malaysia, and other areas in Asia. (Idriverplus 2021)

Some of the technical characteristics of Viggo are presented in the Table 3.

Distance	Charging time	Battery capacity	Hopper capacity	Working hour
30-40 km	4-5 hours	200 Ah	60 L	6-8 hours

Table 3. Idriverplus technical characteristics

Idriverplus was developed in 2015 by Tsinghua University's engineers. The control unit of the vehicle is a field-programmable gate array (FPGA) processor with a microcontroller that is at the heart of the self-driving platform, which began road tests in Beijing last year after receiving the licence from the municipality.

Figure 17. Idriverplus robots (Idriverplus 2021)

4.2 Yeti Move

Every winter, problems with snow became the reason for many delayed flights and stranded passengers all around the world. Autonomous snow ploughs have been tested for the first time at an airport in Norway to make snow clearing more effectively (Figure 18).

Yeti Snow Tech was created by Øveraasen and Semcon in 2015. The company has created autonomous snow removal machines for airports. The first real pilot was demonstrated in March 18 at Fagernes Airport in Norway. In 2019, Yeti Move had the world's largest autonomy contracts for Swedish airport operations with SWEDAVIA. (Yeti Move 2019).

Yeti Move is jointly owned by Semcon. The joint venture has developed an advanced autonomous vehicle control system that is used in environments with high demands on safety, accuracy and reliability. (Yeti Move 2021.)

Figure 18. Yeti Move snow ploughs (Yeti Move 2021)

Capacity	Length	Plough width	Additional info
357500 m^2 / h	20 metres	5 metres	Works in all-weather conditions

Table 4. Yeti's technical characteristics

For autonomous snow ploughing, the control system was designed to make digital plans that are downloaded into the self-driving vehicles. The operators can monitor and control vehicles remotely from the control tower. Two standard trucks used at the airport were retrofitted with a steering actuator, a brake actuator and a throttle control. The navigation and track following are provided with a help of GPS and 4G connection. To increase further the efficiency, the digital plans can be used for simulation and training. (Semcon 2021.)

4.3 ENWAY

ENWAY, the software manufacturer founded in Berlin with the sweeper manufacturer Bucher Municipal, and other partners have started bringing the future on the streets of Singapore. Singapore's National Environment Agency (SNEA) begins pilots of self-driving road sweepers on public roads going towards a sustainable and smart city. The self-driving compact sweeper “Donner” has passed the approval test of Land Transport Authority to be used on public roads (Figure 19). That project was supported by the National Robotics Programme under the Autonomous Environmental Service Vehicles for Singapore grant. (ENWAY 2021)

Donner is developed based on the CityCat 2020 EV by Bucher Municipal. The autonomous sweeper is being monitored remotely, a cleaning routes and times can be determined and modified. Furthermore, during the trial, a driver should be on board to take over the control if necessary. (ENWAY 2021)

Figure 19. Donner street sweeper (ENWAY 2021)

Some of the technical characteristics of Donner presented in Table 5.

Working time	Charging time	Sweeping speed	Additional info
8 hours	2.5 hours	12 km/h	Vacuum-based debris collection system, cyber security functions

Table 5. Donner's technical characteristics

4.4 Autonomous vibratory rollers

The study does not only consist of autonomous sweepers and snow ploughs, as it was mentioned before, the Public Works Department is also responsible for the road construction. That is why, it is important to mention another brilliant innovation, fully autonomous tandem vibratory rollers, ROBOMAG and SAKAI.

BOMAG in cooperation with the University of Kaiserslautern in Germany has created ROBOMAG as a technological study (Figure 20). They have used sensors like LiDAR, GPS and state-of-the-art position. ROBOMAG can be used fully autonomous in defined area. Furthermore, it can be controlled remotely for manual operations. One of the advantages of the autonomous machine is an extraction of the human error by predetermining tasks that it should complete. Another advantage is in its use in mining areas where it can be dangerous to humans.

Figure 20. ROBOMAG autonomous tandem vibratory roller (Roads&Bridges 2020)

SAKAI Heavy Industries is a road construction machinery manufacturer that was founded in 1918 in Japan. In January 2020, the autonomous vibratory roller was used in a test project to verify the applicability of 5G data transmission technology at a construction site (Figure 21). The project was conducted by the Japanese government and 5G data technology companies in Japan. It is collaborating with JIG-SAW company in research and development. SAKAI can be operated remotely or pre-programmed autonomously. (Sakai Heavy Industries 2020.)

Figure 21. SAKAI autonomous vibratory roller (Sakai Heavy Industries 2020)

The accurate tracing of coordinates entered in advance ensures that there is no need for special skills of an operator. It has been shown that the autonomous roller does even better job than a human (Figure 22). (Sakai Heavy Industries 2019.)

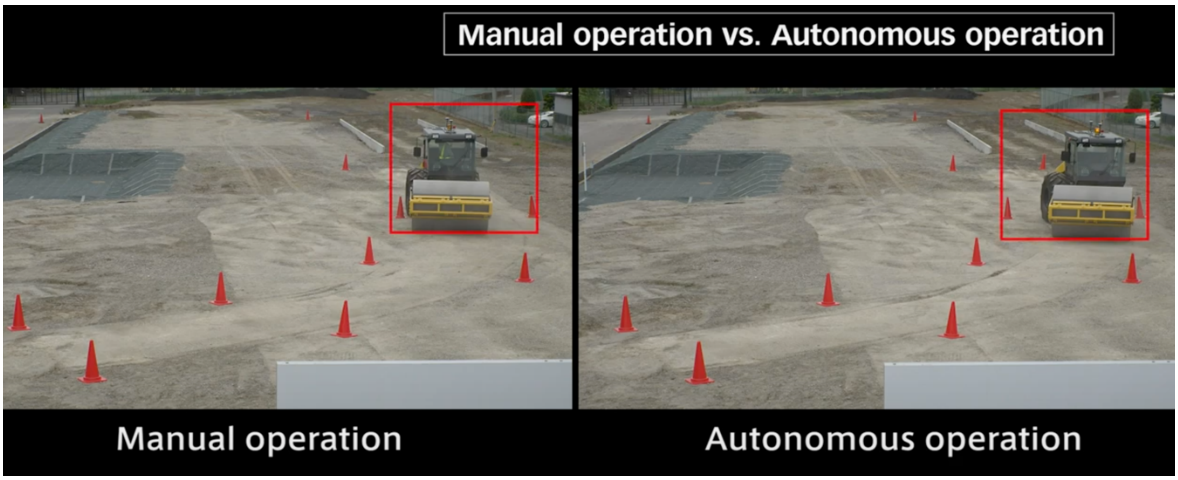

Figure 22. A comparison between manual operation and autonomous operation (Sakai Heavy Industries 2019)

5 Public opinion

5.1 Author’s survey

Living in a digital world brings a lot of opportunities. It is not a problem anymore to communicate with people all around the world, you do not have to walk around with a paper to ask people’s opinions in order to get a sufficient survey. Therefore, for this paper, the online survey method was chosen. Typically, a sample size of 200 and 300 respondents gives an acceptable margin of error (Lyons 2015). The purpose of this survey was to find out the public opinion about autonomous vehicles in the maintenance sector among the age group 20-30 years old. The main Question 1 was aimed to determine whether the public would prefer autonomous machines to clean their streets or a regular driver (Figure 20). Secondly, those who were against self-driving vehicles answered the Question 2 to explain their reasons (Figure 21).

During the survey, the total number of participants was 471 people. Unfortunately, only 200 people answered the poll. That gives around 43% of the response rate, which can be considered as a good result. The age group was 20-30 years old, both female and male.

5.2 Survey result

- Question 1: Would you trust autonomous machines to operate our street, or you think that human can do a better job?

Thus, 158 people voted for autonomous machines and 42 against them. That gives us 79% and 21% respectively. The result is shown as a pie chart in the Figure 19.

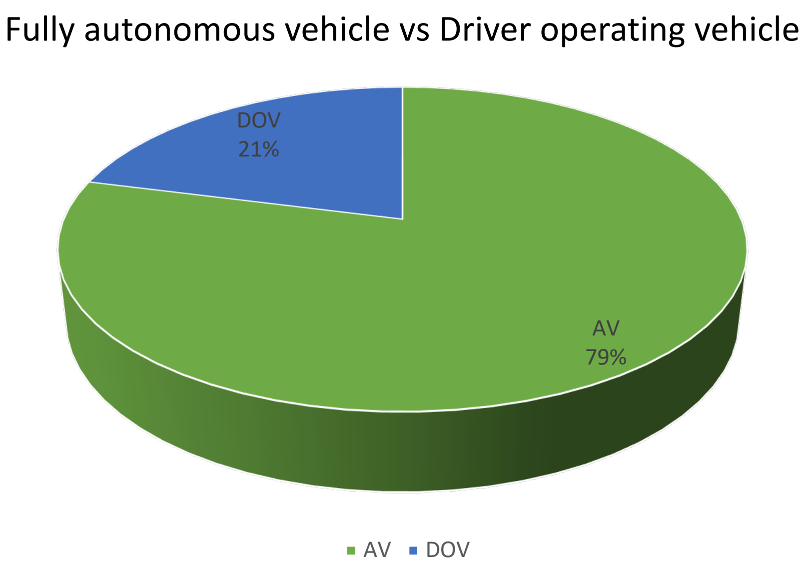

Figure 20. Question 1: Would you trust autonomous machines to operate our street, or you think that human can do a better job?

- Question 2: What was the main reasons for your answer?

Overall, the question was open, thus, it did not have any options to choose from. As a result, only two reasons were named, the loss of jobs and a general distrust towards self-driving vehicles. The respondents' answers were divided into three main categories, where the third category is both mentioned, and presented in the Figure 20 as another pie chart.

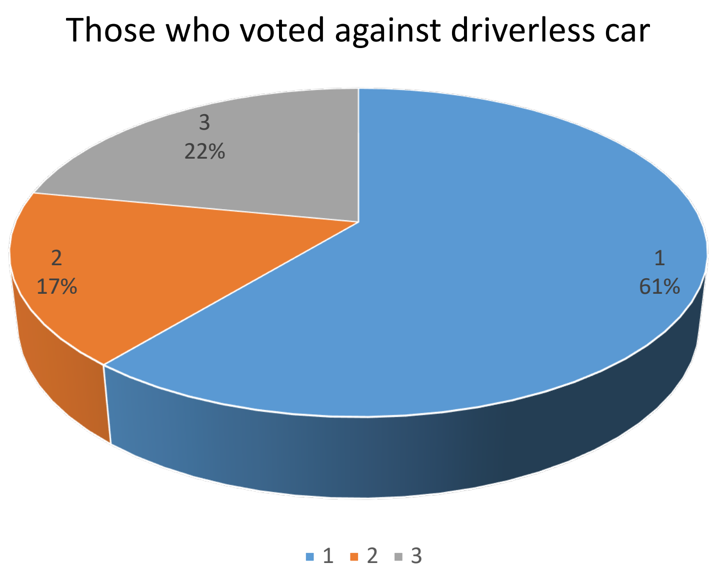

Figure 21. Question 2: What was the main reasons for your answer? (1 – loss of jobs, 2 – distrust, 3 – both reasons)

Several of the respondents' comments are presented as an example in the Figure 22.

Even though autonomous machines help humans a lot, they cannot be as good as them.

In my perspective, there are so many scenarios in the streets that could create problems for robots. To control those problems, we need to change the roads, sidewalks, road signs, which could be more expensive.

I trust robots and I think they can be more effective, because they are designed for the task. But I am completely against machines taking over the humans.

Figure 22. Answers examples of the respondents to the Question 2

5.3 Discussion

In conclusion, the majority has been positive towards the autonomous public area maintenance machines like self-driving street sweepers or snow ploughs. Although, during the survey, respondents had several questions that will be discussed in this paragraph and the personal opinion will be given.

Firstly, as 61% are worried about the driver's job loss, it is important to mention that there will be at least one operator who will truck or even control the vehicle remotely. For that reason, some of the drivers could retrain and do not necessarily lose their job. Furthermore, a safety driver will be a necessity at the trial periods to be able to take immediate control if required.

Secondly, people concerned about either the safety or the effectiveness. There are those who think that humans are better workers than robots. Without a doubt, human eyes are marvellous and capable of reacting quickly in different situations. According to Neumann (1989), perception-reaction time (PRT) of a human varies from 1.5 seconds to 3.0 seconds, depending on the type of a roadway (Koppa 2000). Autonomous vehicles equipped with Lidars or Radars are capable of reacting with a speed of 0.5 seconds (Hammerschmidt 2019). Moreover, sensors make millions of measurements and provide an enormous amount of data to improve the machine's work.

6 Conclusion

6.1 Reasons for implementation

After the research process, the key reasons for implementation were provided. They have been divided into three main categories – ecological, economical and safety, as the most fundamental ones for the municipality. This thesis has been written during the pandemic situation caused by the Covid-19. That added one more advantage of the autonomous operating machines, as it covers both economical and safety factors.

6.1.1 Ecological

Urban air pollution is the most critical health concern of the developed cities. The world health organisation lists that over 4 million premature deaths every year on our planet is actually linked to the illnesses that are originating from urban air pollution. All of the heavy equipment like dust control truck, mechanical sweeper, suction sweeper driving with a little speed on the street and burning around 20 litres of diesel fuel every hour. That gives us 150 kg CO_2/ 1000 m^2 emissions. (Trombia Free launching 2020). As you can see there is a paradox – heavy equipment that gets rid of dust, pollutes our planet with CO_2 emissions. That gives us another advantage of autonomous vehicles, as they are going to be fully electric.

There was a recent research made by the University of Michigan. They have carefully examined two types of CAVs, powered by internal combustion engines and battery-powered electric machines. The vehicles were combined with three types of sizes of sensors and computer subsystems to create six scenarios. (Tech explorist 2018.)

As a result, the important finding was that the electric vehicles have 40% lower greenhouse gas emissions than combustion-powered ones.

Another ecological problem is water consumption. There are no inhabitants on Earth who do not need water. Sometimes we forget that water is not renewable resource, and we need to find ways to reduce its consumption. Most people don't realize the quantity of water that a properly operated sweeper can use. A typical sweeper that has a PM10 rating can consume 5600 litres of water a day which gives us over 2 million litres per year. Those are the numbers people need to start worry about. The solution for this problem is a waterless dust removal system.

6.1.2 Economical

There are many aspects that should be considered when talking about the economic benefits of autonomous machines. To begin with, we take accidents into consideration. For instance, car accidents caused by the poor road maintenance or weather conditions like constantly falling snow which affected the quality, or even slipperiness of the road.

About 20000 people a month in Finland get injured because of slipping during the wintertime. Nowadays, people have a better knowledge on where to ask for compensation from the municipality. Therefore, more than 1 million euros a year are paid out in the capital city. (Yle 2015.) Autonomous vehicles could operate 24/7, as they do not care about the weather conditions or time on the clock.

Secondly, one of the problems in maintenance sector that brings us to the usage of unmanned machines is the difficulty of finding the working labour for operating trucks. That is because each upcoming generation have other interests caused by new technologies. The driverless cars will solve that problem by reducing the number of drivers and their salary but bringing the new kind of job in face of operators that will require more technical knowledges.

Another thing to consider is reduced fuel consumption. Almost all of the operating heavy equipment burns around 20 litres of diesel fuel every hour (Trombia 2020). That gives us 200 litres per day and 73000 litres per year. Paying 1,48 euro for 1 litre of diesel fuel, gives the end result of 108000 euro a year per 1 operating machine.

6.1.3 Safety

Undoubtedly, it is important for the vehicles to be safe. Especially, when we think about driverless cars. This is achieved by redundant measurements, as the sensor suite that Trombia Free has, provides millions of measurements in a second. That helps you to get multiple observations of the objects and thus, makes the system reliable and safe. (Trombia 2020.)

6.1.4 Covid-19

It is well-known that the pandemic situation caused by the coronavirus hit hard a lot of industries: food, transportation, tourism, environmental services, public area maintenance services, etc. In the maintenance and environmental services, the main problem is a manpower shortage. However, that led to a sharp increase in research development and monetary investments due to the new higher demand for automatic cleaning and disinfecting solutions. The virus has changed people's perception regarding cleaning standards, giving the preference to the robots than to humans.

For instance, LionsBot Inernational, a company from Singapore, has faced an 80% increase in demand for their cleaning robots since the pandemic. To help cleaners, the autonomous UV-light disinfection robots can clean big areas at the high-risk places, such as shopping malls, hospitals, airports, etc. (Teh 2020.)

6.2 Possible challenges

The industry of self-driving machines is growing day by day. While autonomous machines have many advantages, there are some challenges that manufacturers face before rolling out the autonomous vehicles on the road. Firstly, road conditions can be highly unpredictable, they could be smooth and marked, but also have some potholes or undefined lane markings. Furthermore, AVs can face some difficulties on the road where they would have to drive not only with other self-driving vehicles, but also with human drivers who may be breaking traffic rules (Gupta 2017). Of course, there are other points to consider like cyber security, legislations, maintenance of the machines, which will be discussed further.

6.2.1 Cyber security

In order to replace a human from the steering wheel, the autonomous machines use AI systems. Unfortunately, like any other IT system, it can be vulnerable to attacks that can disrupt the normal functioning of the machine. Even a little change in the data like a paint on the road or a sticker on the traffic sign can mislead the vehicle (Figure 22). (ENISA 2021.)

Cybersecurity of autonomous machines usually viewed as the security of digital systems. Therefore, cyberattacks against the AVs are not only related to the AI features, but concerns the underline digital infrastructure as well. That is why, the AVs should be designed and implemented not only by different IT scientists and engineers, but by experts in ML, cybersecurity and automation that would work together from the very beginning. (ENISA 2021, 8.)

Figure 22. Example of the class spoofing on a TSR model (ENISA 2021, 42)

Figure 22 shows the result of cyber-attack on the Traffic Sign Recognition model. On the top picture a normal reaction is presented, the “keep right” sign was correctly detected. Although, on the bottom picture there is a result of the TSR system on the adversarial image, where the sticker on the sign made the model incorrectly read it as a “priority road”. (ENISA 2021, 42.)

It is important for the automotive industry to reinforce their security, for example, by using standardised solutions, or to share studies in cybersecurity between each other and work systematically together for reaching the common goal – a full safety. (ENISA 2021, 7.)

6.2.2 Maintenance

Every machine needs maintenance at some point, and autonomous one is no exception. Although, it would need another approach than conventional practices. If Level 4 will ever be a reality, the driver will be fully eliminated from the wheel. That would be problematic if the vehicle will face a failure on the road and would require an immediate intervention of the human. (Joshi 2019.)

Another issue that might appear is the failure of the sensors themselves, they can get damaged and thus, collect inaccurate data (Joshi 2019). That could lead to the hazard situations on the road. One solution could be to always have an operator or a safety driver inside of the vehicle. Another thing to resolve this problem is the predictive maintenance that was achieved with a help of Artificial Intelligence.

6.2.3 Legislation and regulations

One of the main challenges for driverless vehicles is lack of common legislations and standards for operating them fully autonomous. A unified safety standard will certainly give both car manufacturers and consumers the confidence in autonomous machines (Hammerschmidt 2020).

Below were presented some of the practices of the AV industry in the EU and around the world, aimed at developing legislation:

- Australia. The National Transport Commission (NTC) is considering changing some of the driving laws in order to support self-driving cars. The guidelines for trial pilots of autonomous vehicles have been published. (Dentons 2021.)
- China. China's National Development and Reform Corporation (NDRC) and its five key missions in the "Strategy for Developments of Intelligent Vehicles" (ENISA 2021, 13.)
- Germany. An unpublished draft law on autonomous driving was presented at the Chapter Event "Safety & Regulation", completed by a company The Autonomous (Hammerschmidt 2020). Later, the German Federal Ministry of Transport and Digital Infrastructure has published a draft legislation for fully autonomous vehicles on 10 February 2021 (Freshfields Bruckhaus Deringer 2021).
- South Korea. The Autonomous Vehicles Act, which takes place from May 1, 2020, provides support and infrastructure for the AVs. (Dentons 2021.)
- Singapore. The leading country on the level of preparedness, public acceptance and legislation of AVs. Also, have started the trials of AESVs in three designated areas.
- USA. The Department of Transportation released the Automated Vehicles Comprehensive Plan. (Dentons 2021.)

Although public service vehicles are also autonomous vehicles, there should be separate legislation for their operation, which will take into account their speed, operating time and area. Moreover, it is likely that these vehicles will always have a remote operator compared to a self-driving car.

7 Summary

The study introduces the reader to autonomous vehicles, describes their history and the way how it works. One of the reasons for that is to improve both the knowledge and the trust towards self-driving vehicles. As it was revealed in the survey, 79 percent of young people are ready to see autonomous sweepers or snowploughs operating their streets. Another 21 percent are worried for drivers' jobs to be overtaken and doubt that Artificial Intelligence can do a better job.

The information about companies and their products participating in Espoo's future pilots are presented for the representatives to contribute to projects with extended knowledge. Trombia Free, a promising street sweeper that became known all over the world, will start its first pilot in Espoo this April. Unfortunately, there is no information about the date of Lumebot's trial snow plough, but it is still a beneficial collaboration. The last but not the least interesting future project is an implementation of Aalto University Autonomous Systems' machines for agriculture and forestry.

Without a doubt, there are many other autonomous solutions that could be implemented in public area maintenance. For example, greeters with automated distribution of de-icing material. As it turned out, drivers do not know the exact amount of salt or sand that they use per time, and one operator can spend more than needed. Thus, this solution has both economic and ecological advantages. The topic of autonomous solutions is very broad, and there are almost no limits to the equipment's improvement. Therefore, this work has only considered the existing autonomous machines with the reasons and challenges of their implementation.

To summarise, autonomous machines are useful due to the lack of manpower and their 24/7 working hours. They will be especially beneficial in the parking spaces, universities, parks, and sidewalks, where the integration with other moving obstacles is minimal. However, in order for them to be operated on the main streets, a safety driver is required.

One of the main problems of the industry is a lack of united legislation and regulations. Many countries all around the world are trying to solve it by moving towards the innovative future with AVs pilots, and Finland is no exception.

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