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Faculty of Electrical Engineering
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BACHELOR THESIS

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VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

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A KOMUNIKAČNÍCH TECHNOLOGIÍ

DEPARTMENT OF FOREIGN LANGUAGES

ÚSTAV JAZYKŮ

NEW TECHNOLOGIES IN TRANSPORTATION

NOVÉ TECHNOLOGIE V DOPRAVĚ

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VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

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bakalářský studijní obor **Angličtina v elektrotechnice a informatice**
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POKYNY PRO VYPRACOVÁNÍ:

Uveďte vybrané nové vznikající technologie pro oblast dopravy (autonomní vozidla, nové druhy pohonu aj.), základní technický popis jejich fungování. Dále se zaměřte na společenské (etické, právní aj.) a ekonomické aspekty a dopady užití těchto technologií.

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ÖZGÜNER, Ü, Tankut ACARMAN a Keith A REDMILL. Autonomous ground vehicles. Boston: Artech House, c2011. Intelligent transportation systems. ISBN 978-1-60807-192-0.

SONG, Houbing, Ravi SRINIVASAN, Tamim SOOKOOR a Sabina JESCHKE. Smart cities: foundations, principles, and applications. Hoboken, NJ: Wiley, 2017. ISBN 978-1-119-22639-0.

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Abstrakt

Elektrické vozidlo je lepší náhradou vozidla s vnitřním spalováním, zachovávaje si svůj účel. Elektrické vozidlo nabízí vylepšení výkonu, může vyprodukovat maximální výkon během sekund, bez potřeby převodovky, čímž minimalizuje ztráty na výkonu. Jednoduchý dizajn motoru s jedinou pohybující se částí snižuje náklady na údržbu a celkové opotřebení. Tepelní účinnost vozidla s vnitřním spalováním činí 38 %, v porovnání s 90 % efektivitou proměny elektrické energie na výkon, ukazuje to dominanci elektrického vozidla, v případě že se jedná o výkon a možnosti motoru. Je známo, že vozidla s vnitřním spalováním znečisťují životní prostředí svým procesem spalování, produkcí 67 tun oxidu uhličitého za celý svůj životní cyklus, v porovnání s elektrickým vozidlem, které přímo svým chodem neprodukuje žádné emise, jehož výrobní emise a emise z elektrické výroby, jsou nižší o 50 %. Spolehneme-li na čistší zdroje energie, emise na životní cyklus vozidla mohou být sníženy až o 300 %, nahrazováním znečisťujících tepelných elektráren, čistšími zdroji elektrické energie. Z hlediska bezpečnosti v dopravě, od roku 2001 zaznamenala Evropská unie více než 50% snížení úmrtnosti na cestách s prosazováním pokročilých asistenčních systémů pro řidiče. Má v zájmu tuto úmrtnost dále snižovat testováním a zaváděním nových systémů (eCall, systémy pro předcházení kolizím, …). S pokročilými asistenčními systémy pro řidiče je veřejnost jen pár let od prvních autonomních vozidel, která mohou zlepšit způsob cestování, jak ho nyní známe. Jsou limitovány pouze jejich bezpečností, technologickými chybami a zákonnou odpovědností.

Klíčová slova

Elektrická vozidla, redukce CO_2, zvýšená efektivita, pokročilé asistenční systémy pro řidiče, eCall, autonomní vozidla

Abstract

Electric vehicle is a better replacement of internal combustion vehicle, while maintaining its purpose. An electric vehicle offers enhancements in power, it can produce maximum power in seconds, without the need for transmission, minimizing losses in power. A simple design of its engine with single movable part reduces maintenance costs and overall wear and tear. Internal combustion vehicle's 38% thermal efficiency, when compared to 90% energy conversion efficiency. showing dominance of electric vehicle in terms of power and engine capabilities. It is known that internal combustion vehicles are polluting environment with their combustion process, producing 67 tons of CO2 emissions per life cycle of the vehicle, in comparison to electric vehicle that does not directly produce any CO2 emissions, its manufacturing and upstream emissions are 50% lower. Depending on cleaner sources of the energy, emissions can be lowered by more than 300% per life cycle of vehicle by replacing polluting heat power plants with cleaner energy generation solutions. In terms of safety in transportation since 2001 European union recorded more than 50% reduction in causalities on the roads with enforcement of advanced driver assistance systems. It tends to further reduce these causalities by testing and implementing new systems (eCall, collision avoidance systems,…). With advanced driver assistance systems society is only few years from first autonomous vehicles that can improve way of transportation we know now. Limited by their own security, technological faults and law liability.

Key words

Electric vehicle, CO_2 reduction, increased efficiency, advanced driver assistance systems, eCall, autonomous vehicle

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1. Introduction

People have always wanted to travel longer distances faster and in a more comfortable way. Doing this on foot was possible, however, largely ineffective. This fact made them think about new methods of transportation. From ancient times, when people needed to travel, across the river, lake or later sea, they needed a vessel that could transfer them across the water. First inventions of this type were simple canoes from tree logs; later people started building boats from planed lumber with better capacity, to transport more materials and people. The same problem arose on the mainland, travelling on foot was slow, consequently, to that people learned how to tame and ride horses, mules, camels or even elephants. These animals contributed in reduction of travelling times and increased the efficiency and amount of transported materials and people, they were also used to doing different tasks, including transportation of materials, goods and people, working on fields and fighting in wars. Up until present times, means of transportation have passed through numerous changes and innovations; steam powered trains, boats and carriages, first cars with combustion and electric engines or first flights of flying machines. Nowadays we take aeroplanes, ships, trains, cars and buses for granted, while for people living in times when those machines were invented and firstly put into use, it was certainly a technological improvement. We experience the same excitement and amazement as people from the past did, when we learn or hear about new technologies and innovations in transportation, for instance: faster trains, planes or cars, driving assistance services contributing to safer transportation, parking assistance, hyperloop transportation service, electric cars or autonomous transportation. These innovations will make simple movement from one location to another faster and more comfortable for people. Current development in transportation offers cleaner and effective electric vehicles. How do they compare to normal internal combustion vehicles and are they really going to be beneficial for the future?

Advanced driver assistance systems are making travelling safer and shifting the society slowly towards driverless transportation with huge benefits and improvements to offer however, with new advancement in technology comes certain degree of uncertainty and possible exploit. Autonomous vehicles are tested in several states across the United States of America. In a several decades they might slowly start being legally utilized by people. By then problems and possible threats must be acknowledged and solved. This thesis will provide comparison of electric vehicles and internal combustion vehicles, contribution of advanced driver assistance systems towards safety on the roads and overview of autonomous vehicles.

2. Electric and combustion engines

2.1 The rise of the Engine

Prior to Industrial Revolution, the size of settlements inhabited by people was reduced to distances reachable on foot or horse. However, with the development of motorized transport – in particular steam and electricity powered trains – settlements experienced enormous sprawl further from urban centre and they all became connected by motorized trains, trams and cars.

In 1801, Cornish mine manager, Richard Trevithick, build the first steam-powered carriage, considered to be the first motor vehicle or automobile, bringing an end to the era of horse transportation and starting the era of something much bigger. Consecutive technological breakthrough in technology of motor vehicles took place in 1834, when an American blacksmith and inventor Thomas Davenport developed the first electric motor fed with direct current. This advancement inspired inventors to develop a large amount of non-rechargeable battery-powered vehicles, one of them being a battery electric vehicle invented by Robert Anderson, who later founded the Detroit Electric. These electric vehicles were cleaner, more efficient, quieter and therefore more desirable to drive than their steam-powered counterparts. One significant aspect limited them. It was the dependence on non-rechargeable batteries. Thirty-one years later, in 1865, Frenchman Gaston Planté developed the first rechargeable lead-acid batteries, causing a massive improvement in transportation and development at that time. In the year 1897, in the same country, France, regenerative braking was developed by Alexandre Darracq, which dramatically improved energy efficiency and the range of electric vehicles [1, p. 70]. French electric vehicle and battery manufacturer, Bouquet, Garcin & Schivre, soon build an electric vehicle capable of achieving record range of 290 kilometres per one charge and world record of 110 km/h. It was the first car ever to break three-digit speed, which occurred in France [2]. While development of electricity powered vehicles was in process of improving, in the year 1885, more than half a century later after the first constructed electric vehicle, German engineer and technician Karl Benz designed the first vehicle with internal combustion engine (*Figure 1*).

Its success was not immediate amongst general public. These vehicles, much like steam powered vehicles, were noisy, polluting and caused major public disturbance. In addition, starting early internal combustion engine vehicles required you to put some force behind the vehicle’s crank-shaft, comparing this to immediate start of electricity powered vehicle, consumers were drawn to early electric vehicles instead of new vehicles with internal combustion engine, preferring easier and safer alternative. However, one significant disadvantage of quieter and cleaner transportation did not help their further development and production: it was the price of electric vehicles. The price of one electrical automobile one hundred years ago, was equivalent to a modern-day Rolls-Royce – 320,000 USD. This luxury was, however, only available to wealthier classes, while the majority of buyers, middle and lower classes were unable to afford to buy the aforementioned vehicles. However, electricity powered vehicles were eventually detruded from car market, by internal combustion vehicles.

Figure 1: The original "Benz Patent Motor Car", 1886 - the world's first automobile [41]

After the year 1912 three major factors contributed to gradual replacement of electric vehicles with internal combustion vehicles. First major downside to electric vehicle was its limited range. As mentioned above, maximum range capability of 290 kilometres per one charge was insufficient for short city driving. Electric vehicle’s early success was experienced in America, because of a limited number of paved roads to major urban areas, compared to European road development – being years ahead of American roads – the car market was not oriented in short-range travelling however, primarily for intercity i.e. long-range travelling.

The revolution to the car market came with the introduction of Henry Ford's Model T, transforming automobile industry from producing one car at a time to the production in series. Ford Model T was first introduced in 1909 at the price of 850 USD (equivalent to 23,620 US dollars in 2018 prices, according to Bureau of Labour Statistics consumer price index calculator) [3]. Henry Ford accomplished reduction of costs by focusing on mass production of his vehicle. Electric vehicles were not able to benefit from cost reduction provided by mass production. High cost of a battery, powering the vehicle, was significantly weakening electric vehicle's position on car market. Henry Ford and his internal combustion vehicle penetrated mass market, and suddenly electric vehicles manufacturers became less preferred [2].

Third and the last problem holding back the expansion of internal combustion vehicles was the necessity to start the car with crank-shaft – potentially excluding weaker and older people from buying. In 1911, Charles Kettering a invented solution to this problem, by replacing obligatory crank-shaft with starter motor (electric motor) [4]. Eventually, by 1930s, electric vehicles disappeared from car market allowing vehicles with internal combustion engine to remain a dominant technology in car industry for decades.

2.2 Improvements offered by electric cars

Nearly one decade later, technology of electric vehicles starts to improve and slowly outperform current internal combustion vehicles. The reasons why battery electric vehicles disappeared from car market in the past were mainly technological and economical differences in their fuel system, in particular low travel distance of electric vehicles and the cost of the batteries. With continual technical development, achieved since the year 1930, batteries of electric vehicles are still inferior to the fuel system of internal combustion vehicles. In contradiction to this fact, electric vehicles offer a wide variety of technical improvements in contrast to internal combustion vehicles, in particular: reducing maintenance costs, greater efficiency, enhanced performance, flexible design, zero emissions and decreased noise pollution. Every quality of electric vehicle stems from its mechanical simplicity and nature of electric operation. [1, p. 72].

Main mechanical advantage of electrical engine over internal combustion engine is the fact that for its proper operation it requires only one mechanical movable part, a rotor shaft rotating in relation to stationary parts of engine, thereby demanding less lubrication or working fluids and causing minimal stress between the engine parts. This results in reduced overall abrasion of engine, a lowered number of visits in a car repair service and lower costs for engine maintenance. On the other hand, internal combustion engineering consists of tens of moving parts, requiring a significantly bigger amount of lubrication or working liquids, otherwise its function is at risk of jamming or in the worst case being irreparably damaged. The number of moving parts and self-damaging nature of combustion process contributes to engine's wear and tear. Visits in car repair service to replace worn-out parts or to examine condition of the vehicle are required more frequently. This results in higher cost for repairs that are definitely not cheap. Reduction of maintenance costs is a significant advantage brought by electric engines and provides sufficient compensation for high acquisition cost of electric vehicle.

Lowered maintenance cost is not the only advantage electric engine provides. As stated above, an electric engine has a very simple, lightweight and small construction, compared to combustion engine, and can provide more power despite its smaller and lighter construction. For instance, AC induction engine weighing only 24 kilograms can produce impressive power of 160 horsepower (120 kW) [5]. Compared to a 145-kilogram 8 valve heavyweight block of engine of the same power [6]– the weight stated includes only the weight of the engine block, without the vehicle propulsion equipment.

2.3 Performance differences

Inequalities in engine size, weight and maintenance mentioned in the previous chapter are, however, not the only differences in comparison of electric and internal combustion engines. Great disadvantages of internal combustion engines are their poor torque and power capabilities when achieving a large variety of speeds and, in this manner, requiring transmission and gearing, to utilize its power and achieve the desirable performance and speed. The needs for transmission are reduced when a car uses an electric engine. This is possible as a result of high energy conversion efficiency across a wide variety of performing speeds. In vehicles using electric engine efficiency is measured by intake of electrical energy to work produced. In electric engines, the normal running efficiency ranges from 85 - 90% [7]. In comparison to thermal efficiency of internal combustion engine (measured by heat of combustion of the fuel to work produced) depending on engine type, diesel engine has its peak at 40% and gasoline engine around 20% of efficiency [8]. In relation to power differences, operation of electric vehicle can function without various gearings greatly reducing losses caused by transmission. For further reduction of those losses, typically in combustion engine type cars, a new type of transmission, continuously variable transmission, is utilized primarily in the newer vehicles. Continuously variable transmission is similar to the function of automatic transmission. Its operation is different from conventional automatic or manual transmissions. It does not consist of a gearbox with a set number of gears. Most of continuously variable transmissions operate similarly to alternator. They consists of two pulleys (primary and secondary) and a rubber V-belt connecting them *(Figure 2)*. Each of those two pulleys has a fixed part and a movable part allowing infinite variability between highest and lowest gears without noticeable shifts in gears. Changing gear ratios works more smoothly and results in continuously variable transmission's ability to send an adequate amount of power from engine to the vehicle's propulsion system to ensure the best possible fuel-efficiency. Saving fuel is not the only advantage of continuously variable transmission. As a result of improved gearing, either electric or combustion vehicle equipped with this transmission will benefit from having improved acceleration along with smoother ride – by better responding to changes in speed and eliminating disturbance caused by shifting gears [9].

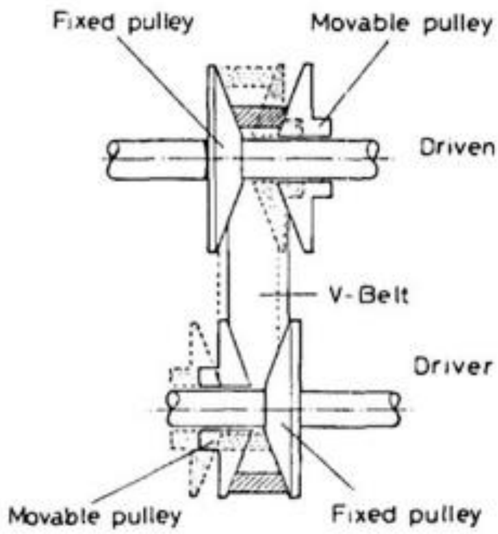

Figure 2: Principle of V-belt pulley continuously variable transmission [9, p.391]

3. The impact of electric vehicles on environment

3.1 Emission reduction

Many people believe in myths about electric vehicles producing as much carbon dioxide (CO_2) and other nature harming emissions as conventional internal combustion vehicles. We know for fact that this myth is false, even after comparing all of manufacturing emissions, pollution as a result of electricity generation and fuel production, emissions produced by vehicle or any other related pollution. A two-year study performed by The Union of Concerned Scientists (UCS) [10] - focused on determining, for how many emissions is an electric vehicle, compared to an internal combustion vehicle, responsible for. Their study concludes: “Electrical vehicle generates half the emissions of the average internal combustion vehicle, even when accounted for pollution from battery manufacturing [10, p. 12].” Half of the overall emission reduction is considerable amount for an electric vehicle that does not produce any emissions by driving. All emissions are produced elsewhere, mainly by manufacturing the vehicle and electric energy generation.

3.2 Manufacturing and electricity generation emissions

Manufacturing emissions of electric vehicles are much higher than those of internal combustion vehicles. The same study performed by Union of Concerned Scientists, says:

> Manufacturing a midsized electric vehicle with 84 mile (135 kilometres) range results in about 15% more emissions than manufacturing an equivalent internal combustion vehicle. For larger, longer-range electric vehicles that travel more than 250 miles (402 kilometres) per one charge, the manufacturing emissions can be as much as 68% higher [10, p. 21].

A sixty-eight percent increase in emissions, even before an electric car had ever been driven is definitely a negative start for a vehicle, however, as mentioned above electric vehicles do not produce any emissions when driven. The report of Union of Concerned Scientists continues: “Longer-range electric cars make up for their higher manufacturing emissions within eighteen months of driving — shorter range models can offset the extra emissions within 6 months [10, p. 22].”

The above mentioned report claims that electric vehicles can compensate for initial manufacturing pollution in less than two years. Considering the fact that internal combustion vehicles continue to produce more emissions with their combustion process after leaving manufacturer, compared to electricity conversion of electric vehicle that does not produce any emissions. The process of generating electric energy produces emissions similarly, contemporary heat power plants generate a portion of generated electricity, using coal, oil and gas and are considered the most polluting electricity generation process. Wind, solar, hydro, biomass and nuclear generated electricity is, in terms of emissions, superior to heat power plants. The amount of emitted emissions depends on how electric energy is generated in the region or country that your vehicle was manufactured or is currently powered in [11, pp. 9 - 10]. Figure 3 presents data from [10] about life cycle emissions of an average midsize internal combustion vehicle, compared to a midsize 84 mile range electric vehicle. The graph contains life cycle of internal combustion vehicle manufacturing and operating emissions. Manufacturing, upstream (operating) and additional battery manufacturing emissions of electric vehicles are depicted in three different values. Each of these three values is affected by electric energy generation means, specifically a ratio between cleaner sources of energy – renewable (hydro, solar, geothermal and biomass) and nuclear sources – and polluting sources of energy (coal, gas and other fossil fuels). Internal combustion vehicle (with 67 tons of CO_2 emitted) has the highest life cycle emissions. Compared to the highest emission value (45 tons of CO_2 per life cycle) of electric vehicle manufactured and charged in power grid (Western Electricity Coordinating Council: Rockies) generating 87% electric energy from polluting sources of electric energy [10]. Considering the data provided from Figure 3, we see 50% reduction of emissions in a more polluting instance, greater reduction happens when electric energy is generated from cleaner sources, for instance 64% ratio of cleaner energy generated in Northeast Power Coordinating Council grid in, Upstate New York. We can observe more than 300% reduction of emissions, compared to emissions of internal combustion vehicle [10].

Further reduction of emissions from generating electricity is possible by replacing polluting heat power plants with cleaner sources of energy by either government policies or citizen initiatives. Further reduction of emissions from electricity generation is possible by installing a solar panel on the roof of the electric vehicle. Not only reducing emissions by generating energy from the sun, but also increasing vehicles range and shortening charging time, given sunny, cloudless conditions throughout the day.

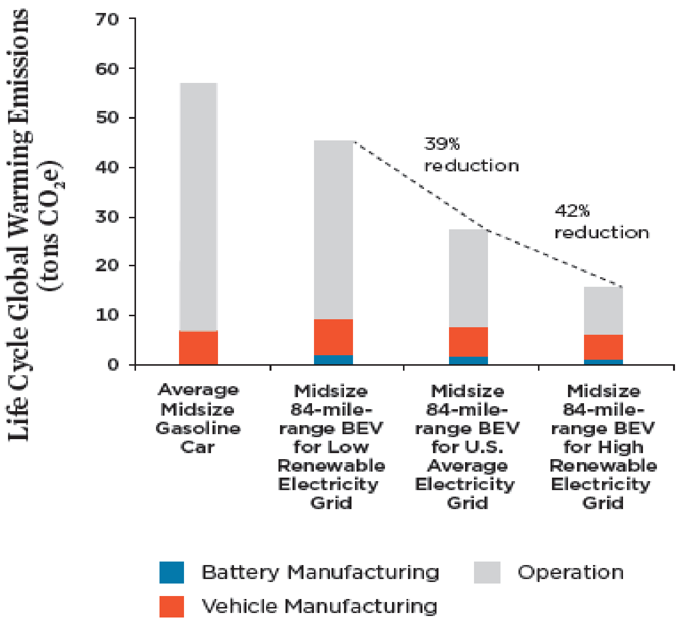

Figure 3: Life cycle global warming emissions [10, p. 26]

3.3 Recycling of vehicles and batteries, possibility of battery reusability

Electric and internal combustion vehicles are made from the same raw materials e.g. steel, aluminium or plastic. Additionally, electric vehicles contain a battery as a source of their power. At the end of the life cycle, both vehicles require the same amount of energy for their disposal. The only exception are batteries from electric vehicles, which can be reused for various purposes, including commercial and residential electricity storage and other uses not concerning vehicles. Materials inside batteries can also be reused in other batteries or different equipment. Reused or recycled batteries further reduce the amount of emissions in our atmosphere, long after not being utilized in a vehicle that they originated from [10, p. 9 (Box 1)]. Electricity generation emissions studies do not consider possibility of reusing and recycling electric vehicle batteries, which would further reduce emissions of electric vehicles.

4 Economic and political effect of electric transportation

4.1 Cost-effectiveness of electric vehicles

Comparing electric and internal combustion vehicle's performance, maintenance or environmental sustainability, it is evident that electric vehicle surpassed its counterpart in the above mentioned properties. The prices of both vehicles are different, when discussing costs for vehicle from dealership and driving costs. Electric vehicles cost significantly more, primarily battery contributes the most to high price. On the other hand, electric vehicle drives at a fraction of a price for fuel to power gasoline vehicle. To determine whether electric vehicle is a better cost-efficient equivalent, we must take several aspects into consideration. First is the cost of the battery, which contributes as the highest allowance on the final price of the electric vehicle. According to the information presented by Pistoia:

> Cost of batteries for electric vehicle applications will decrease significantly over the coming years. It is likely that the following three factors will contribute equally to lowering the price of Li-ion vehicle batteries:
>
> - Increased process knowledge and manufacturing scale.
> - Engineering advances in battery design.
> - Introduction of new materials with increased performance [11].

With increased demand for electric vehicle batteries and consequently increasing number of battery manufacturers (reduction of transportation expenses) will cause its price to drop even lower.

Current electric vehicles do not compare successfully to internal combustion vehicles in terms of maximum range capabilities the reason being insufficient storage of energy for long-range travelling. Maximum range of an electric vehicle differs from the lowest ranges of 300 kilometres (Renault ZOE, range estimated under the New Worldwide harmonized Light vehicle Test Procedure WLTP test cycle) [12] to the highest range of 603 kilometres (Tesla Model S Long Range, under WLTD test cycle) [12] in one charge. When discussing range capabilities average daily travel has to be considered, depending on the region, infrastructure or driving in rural or urban areas, average daily travel varies. Data from the National Household Travel Survey [13] show that electric vehicles are able to handle 80% of all daily driving in the USA. A study conducted by Roger van Haaren in 2012 [14], shows that when driving distance is accumulated throughout the day around 95% is below 193 kilometres, while 99% below 400 kilometres. Therefore, only overnight charged electric vehicle (Renault ZOE) with the range of 180 – 300 kilometres, depending on conditions (weather, traffic, air condition turned on or off) is able to satisfy 83 - 95% of daily travels. And Tesla´s Model S Long Range with its longest range of 603 kilometres can satisfy more than 99% of daily travel distances, assuming matching or better conditions for necessary range. Single trip evaluation in this case is not the best way to evaluate cost-efficiency. Limited public charging stations have significant impact on deciding between internal combustion vehicle and electric vehicle. Incomplete charging infrastructure is not the only problem of current electric vehicles, even with sufficient density of public charging stations to compensate for lower range, charging electric vehicle takes significantly longer time than to fill up tank of internal combustion vehicle. In highway rapid charger it lasts 30 minutes when charging 10 kWh battery from 1% remaining power to full capacity. Charging times vary with different battery capacities, charging power of charger, charging power of the vehicle and starting charge level of battery. As shown in this chapter, electric vehicles are cost-efficient in utilizing their cheaper energy costs and possibility to satisfy up to 95% daily travels done by internal combustion vehicles. However, currently insufficient charging infrastructure and developing battery technology do not allow to utilize vehicle´s proper application. Therefore, in terms of long-range travelling and energy storage its applications are limited [14].

4.2 Economic growth

Automobile industry launched economy of the USA between the years 1925 and 1950 to global superpower status, maintaining this status to present day. After the Second World War, Japan, as former industrial power, faced post-war recession, having massive negative impact on their economy. In the 1970s their automobile industry started to prosper with the help of US energy crisis in progress, Japanese smaller and fuel-efficient vehicles became demanded more than bigger, more gas consuming American vehicles, eventually expanding to foreign countries. By 1980 Japanese automobile industry surpassed the American, becoming world leaders in automobile industry [1, p. 185]. From history it can be observed that automobile industry is undoubtably one of major economy drivers of a country. We can see the same development as in 1970s. Automobile industry is shifting East, with big automobile brands (Nissan, Mitsubishi, Toyota) along with new brands, BYD from China, Reva from India, Proton (owning Group Lotus) from Malaysia, developing and manufacturing small electric vehicles. In the meantime, big European companies (Fiat, Volkswagen, Mercedes-Benz) are not doing

enough to match rapidly expanding Eastern electric vehicle market, slowly expanding west and eventually detruding them from their position on car market [1, p. 187].
Manufacturing new electric vehicles will create thousands of manufacturing and engineering jobs, which are expected to come at expense of ageing internal combustion vehicle industry. The opportunity of creating and at the same time losing many jobs will encourage governments to support future electric vehicle industry.

4.3 Government involvement

The popularity of electric vehicles is on its rise and insufficient charging infrastructure will pose a serious problem, when the demand for electric vehicles extends beyond the capacity of public charging stations. To prevent this shortage, governments have to focus on attracting potential developers to construct new public charging stations. One way of doing so is to provide benefits for investors, architects, designers, builders and developers or contrarily establishing regulations to make non-electric vehicle companies less attracted to invest in running their business in that country. With the result being slow transformation of a country for electric vehicle usage and slowly adapting people to new and better technology. Providing strong environmental and economic benefits of electric transportation to government leaders, giving them a strong reason to focus earlier than the problem arises to promote cleaner and energy-efficient transportation.

5. Advanced driver assistance systems (ADAS)

5.1 History and introduction to ADAS

People have dreamed about self-driving or automated vehicles since first vehicle was introduced to the people in 1886 by Daimler. Aforementioned technological advancement was not possible to achieve nearly 150 years ago, due to insufficient knowledge and technologies. Technologies advanced and in 1960s first modern integrated circuits were created at Massachusetts Institute of Technology (MIT) and used by NASA in Apollo Space Program [15]. After successful implementation and trial of these integrated circuits in Space Program, development of first embedded systems capable to assist drivers when driving or parking started. In 1970 automobile manufacturers started to further develop and later implement embedded systems into vehicles. The National Highway Traffic Safety Association (NHTSA) "… established in 1970, providing national leadership in planning and developing improved driver education, licensing, enforcement, prosecution, judicial and post-adjudication efforts in the United States of America and other United States territories" [17]. Competition among vehicle manufacturers for the newest and safest system has begun. One of the oldest driver assistance systems is Cruise Control system, American engineer Ralph Teeter's invention implemented to Chrysler's Imperial model in 1958. The vehicle's engine revolutions were kept steadily at given value, therefore the speed was maintained the same, using bi-directional screw-drive electric motor under the throttle pedal *(Fig.4)* [16]. In 1962 Mercedes developed a similar device based on maintaining the same velocity under their own brand name, the Tempomat, which is much widely known term to consumers in present days. Implementation of Cruise Control (Tempomat) mechanic into vehicles was presented as an excellent solution to put driver's foot to rest when traveling longer distances on a highway. In 1973, during oil crisis, cruise control became sought after by customers, as a result of high prices of oil. Cruise control helped drivers to reduce the amount of consumed fuel by eliminating inconsistent acceleration and deceleration.

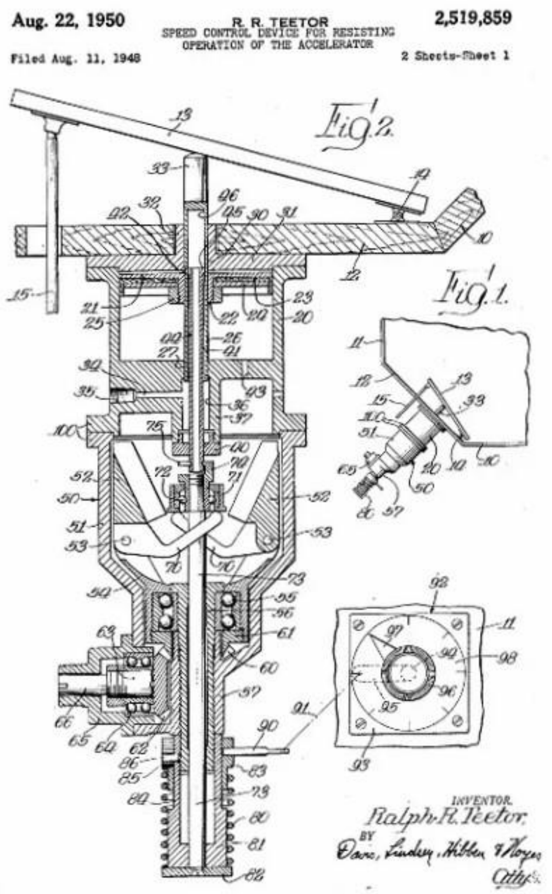

Figure 4: Teetor's patent for Tempomat ("Speed control device for resisting operation of the accelerator") from the year 1950 [17]

Anti-lock braking system (ABS) is another driver assistance system from the first system introduced and implemented. Development of ABS started in early 1920s, first in aircraft industry. The objective of ABS was the same as today, to prevent locking the wheels when during rapid deceleration. Later in 1960s first vehicle with integrated ABS was introduced by Ford, it was Ford Zodiac. One major disadvantage caused that ABS was not further implemented to other vehicles. It was the high price of the system; therefore, it was only installed to premium vehicles as a luxurious auto feature. In 1970s ABS technology got significantly improved and became much cheaper. It became standardized in every car in 1990s. With addition of computer-controlled sensors on each wheel, ABS became even more effective and popular [18].

Last driver assistance system is based on radar technology. From simple parking sensors sensing vehicle's surrounding and assisting to drivers when we are parking to much more complex active sensing configurations of radars, granting information about proximity of other vehicles, warns you about presence of another vehicle in blind spot zone of the vehicle and the latest ones can keep the safe distance from the vehicle in front of you, warn you if the vehicle in front of you if vehicle in front of you unexpectedly decelerates even before you can react. The development of radar began in mid-1930s in Great Britain, Germany and United States, every country had its own model of radar however, it was used only in military service. In the Second World War it helped Allies to win the battle of Britain and throughout the war, radar development advanced considerably, as a result of military demanding stronger and larger sensing distance of radars to detect enemy aircrafts and ships with higher accuracy and sooner than enemy discovers their positions. After the year 1950 a new generation of radars was in process of development. Technological, engineering and science advancements enabled smaller, cheaper and less energetically demanding, compared to previous models [19].

The Cruise control (Tempomat), ABS and Radar technology are driver assistance systems that brought various changes to transportation safety. These systems were further improved to much more sophisticated and advanced systems. At present we have a variety of systems inbuilt inside our vehicles. They perform their protective functions without being noticed or known that they are present, for instance ABS, electronic stability control (ESP), cornering brake control (CBC) or traction control system (TCS) [20]. These systems directly improve performance of vehicles on the road and off road (dirt, gravel or other unpaved surfaces) at any weather conditions [21]. Driver assistance systems that drivers or passengers are aware of and can interact with them while driving, have equal importance in vehicles and passenger safety. Adaptive distance and speed regulation (ACC), blind spot assist (BSD – Blind

Spot Detection), parking assistant and lane departure warning are responsible for warning the driver in an instance of unexpected obstacle while driving or parking. In emergency situations when the driver does not react to the system warning, the system itself will act by slowing down, changing the lane or immediately stopping the vehicle.

5.2 Known and unknown safety effects of ADAS

All above mentioned systems are considered as advanced driver assistance systems (ADAS) according to European Commission's General Directorate for Transport [22]. Safety related advanced driver assistance systems are divided into two broad groups:

- safety effects known
- safety effects unknown

Safety effects known, by definition from article, are positive results from more than one study done in similar road safety context and they statistically prove significant reduction in injuries or deaths caused by road accidents. The report [22] also defines systems with safety effects known, in particular: intelligent speed adaptation (ISA), electronic stability control, anti-braking for motorcycles, event and journey data recorders and including seat belt reminders and alcohol interlocks for repeated offenders and fleet drivers. The last two systems mentioned directly affect the driver, his life and performance [22].

In 1993 European Transport Safety Council (ETSC) was founded. ETSC is non-profitable organization dedicated to reducing number of deaths caused by transportation in Europe that identifies and promotes effective measures to prevent and reduce road accidents and casualties based of international scientific research and practice (known safety effect systems). Data provided by ETSC website [23] show information about road casualties in 32 European countries, Cyprus and Israel. Firstly, data comparison demonstrates improvement of safety on the road from the year 2001 and 2017 (*Figure 5*) [23].

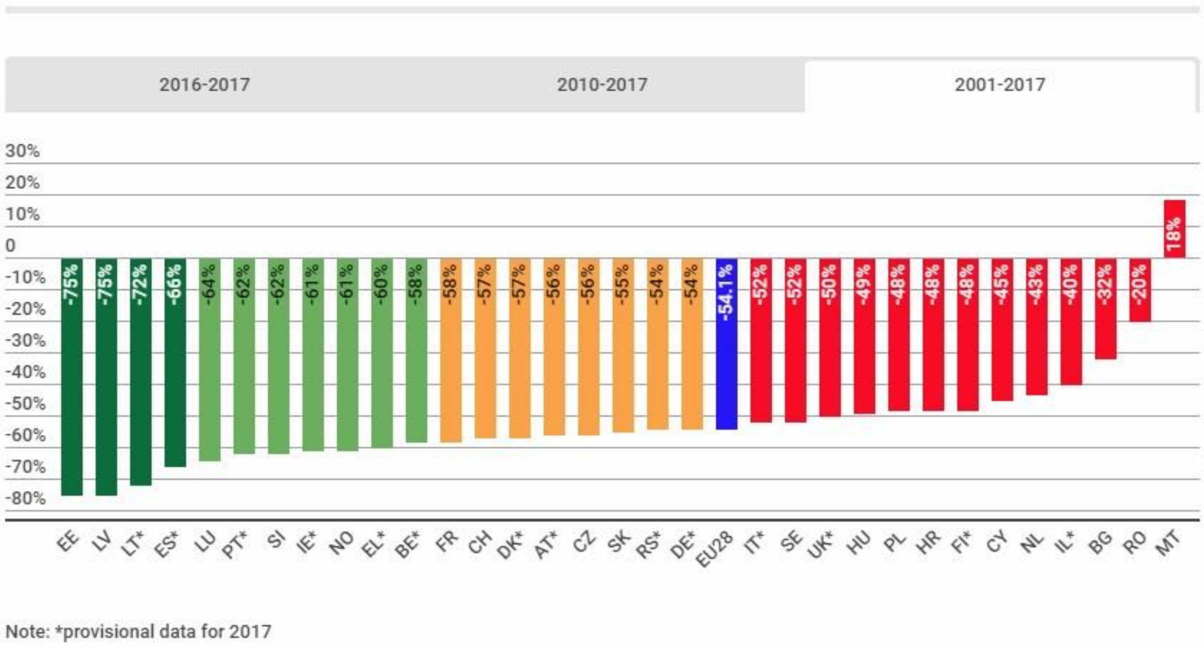

Figure 5: Change in road casualties between years 2001-2017 [23]

Numbers from *Figure 5* prove usefulness and effectivity of ADAS in saving lives. These reductions look promising in a longer period of time. On the other hand, data from previous 4 years (2014-2017) show only a small improvement. From the year 2014 to 2017 reduction of road casualties in European Union was 3%. With regard to European Commission's 10 year plan (from 2010 to 2020) of reducing number of road casualties by 50% [24]. From the year 2010 EU countries achieved overall reduction of 20% in seven years (*Figure 6*). It is highly improbable for European Commission to reach desired 50% reduction by the year 2020. ETSC's 12th Annual Road Safety Performance Index (PIN) Report [24] acknowledges slow progress toward desired results in reducing road casualties and suggests stronger political involvement and urgent measures taken by EU countries. Possible reduction in road causalities can be provided systems with unknown safety effects.

ADAS with unknown safety effects are newly developed and with manufacturer's early tests offering promising future development. Their testing did not yet prove the desired statistical significance as opposed to systems with known safety effects. Two highly promising systems are in this group, eCall and Collision Avoidance system, which benefits, and safety related data are going to be discussed further.

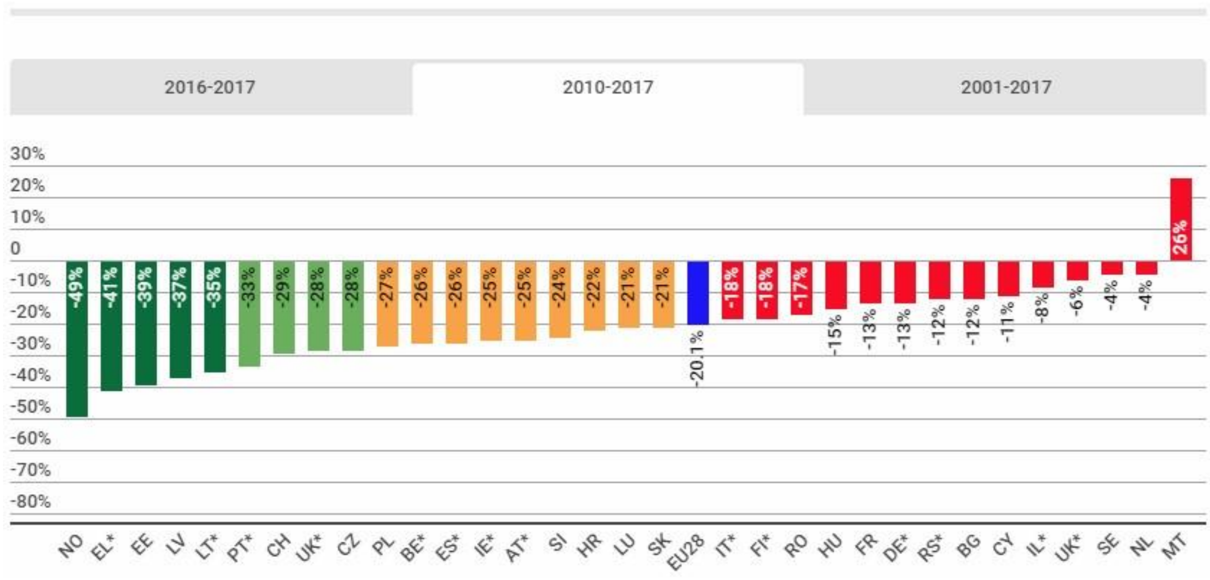

Figure 6: Change in road casualties between years 2010-2017 [23]

5.3 eCall

It is a post-crash care system, essential to ensure immediate automated call to the closest emergency centre and assure faster arrival of emergency services. eCall is built-in device inside the vehicle and it is activated after the accident occurs automatically or by manual activation from vehicle occupants. The main purpose of the system is time reduction from when accident occurs to the arrival of emergency services. In-depth analysis [25] performed in Finland shows overall 3.6% reduction of deaths caused by road accidents. Figure 5 shows the most efficient use of eCall would be on vehicles that eCall was not designed for (motorcycles, quadbikes, mopeds…) as opposed to eCall designed vehicles (buses, automobiles, trucks, vans…). Study determines additional probable death prevention effects of eCall, either for vehicle occupants (5%) and for unprotected road user (1%) despite the Figure 4 showing zero very probable road death prevention. New findings estimate the approximate death prevention to 4 – 8% on Finnish roads [25, pp. 101-102].

Effect	Motor vehicle occupants (N)		Unprotected road users (N)		Overall (N)
	eCall designed for vehicle	eCall not designed for vehicle	Motor vehicle involved	No motor vehicle involved	
Very probable prevention	4.4% (39)	10.8% (4)	0.0% (0)	0.0% (0)	3.6% (43)
Very probable prevention could not be authenticated	94.2% (831)	86.5% (32)	100.0% (233)	100.0% (28)	95.2% (1,124)
Insufficient data	1.4% (12)	2.7% (1)	0.0% (0)	0.0 (0)	1.1% (13)
Total	100.0% (882)	100.0% (37)	100.0% (233)	100.0% (28)	100.0% (1,180)

Figure 7: Effects of eCall on the number of fatalities [25, p. 102]

Preventable deaths included cases of:

- drowning when vehicle fell into the water and occupants were unable to escape from vehicle
- alcohol abuse where passengers were incapable to call emergency while being asleep or under substantial effect of an alcohol, unable to realize the severity of the situation
- injuries to the rib cage slowly causing more serious damage to internal organs, brain contusions combined with breathing problems eventually leading to severe brain injury [23]

Second important feature of eCall is the ability to signalize position of the vehicle in the event of accident reliably and accurately. Satellite navigation is the single method for position determination currently. However, despite its high efficiency and accuracy at position estimation, satellite navigation has several vulnerabilities and limitations rendering its performance unconsistent. Tunnels, urban and mountain areas weaken the satellite signal, together with positioning error sources (satellite component and control component errors, user component error, errors due to media). To eliminate as much of these errors as possible and maintain optimal satellite positioning performance, enhancement to the core satellite positioning is required. Main focus should be primarily on already built-in sensors inside the vehicle that can provide less accurate, but constant location related data, in particular: accelerometers, mobile communication equipment. Especially useful in areas with weak satellite signal (urban and mountain areas, tunnels) [26].

5.4 Collision Avoidance Systems (CAS)

This system is developed for the purpose of monitoring the situation on the road, predict the collision and even before the driver can react to unexpected scenario, CAS will warn the driver or in the worst case scenario apply active braking system to avoid collision [27]. CAS utilizes radar perception technologies, video image perception and processing technology, V2X technology and sensor perception and information fusion technology for its sensing purposes. Each of aforementioned sensing technologies is used for different ADAS:

- **Radar perception technologies** – use of ultrasonic, millimetre wave and LiDAR radars. Simple and inexpensive ultrasonic radars are used in parking sensors, precise millimetre-wave radars are used in adaptive cruise control and other ADAS and LiDAR radar technology has high detection range up to 100 m, high speed, high stability and 3D imaging useful in obstacle avoidance and pedestrian protection [28, p.5].

- **Video image perception and processing technology** – lane recognition and obstacle recognition are examples of these technologies use. Motion based recognition and analysis [28, p. 4].
- **V2X technologies** – are used in information exchange between an environment and the vehicle (road-vehicle and vehicle-vehicle communication). Vehicle-road communication (vehicle-base station communication and GPS navigation) requires the deployment of roadside communication devices. They will transmit data about road accidents, weather, and road curvature and adhesive coefficient to vehicles in their range [28, p. 5].
- **Sensor perception and information fusion technology** – sensors inside the vehicle that monitor dynamics of the vehicle (steering wheel angle, torque sensor and yaw-rate sensor) are used to obtain information on vehicle’s status. Information from these sensors is inaccurate in process of collision avoidance. Information fusion of these sensors with radars, video, GPS and digital maps will eliminate this inaccuracy and improve accuracy of vehicle-vehicle and vehicle dynamic parameter estimation [28, pp. 5-6].

CAS can prevent numerous collisions when installed to every passenger vehicle. The most common collision type is rear-end collision. “Rear-end collision occur when one automobile impacts the rear bumper of the vehicle directly in front of it. Typically, sudden deceleration by the first car initializes the chain reaction in which the following car cannot apply breaks in time (often resulting in multiple-vehicle collision) [29].” Two million rear-end collisions that are reported by police occur on American roads every year, which is a one third of all collisions that occurred in United States yearly [29]. Common cause of rear-end collision is distracted driving, tailgating, intoxication, fatigue of the driver, speeding, weather conditions (reduction of visibility and icy road) and road conditions [30]. In 95% of all rear-end collisions, human error was initiator of all of them. According to Accident Analysis & Prevention [31] 50% of all collision could have been avoided if all vehicles had installed CAS, specifically systems similar to Forward Collision Warning (FCW) and Autonomous Emergency Braking (AEB). Most importantly, collisions with injuries could have been avoided in 56% of incidents [31].

Considerable amount of research is being carried out on collision avoidance systems and technologies. In order to prove their feasibility tests in controlled environment are required, later supported by field test studies. Those will provide final numbers and confirm estimated values.

5.5 Possibilities of installing ADAS systems on older vehicles

A part of European Road Safety Area (2011) Policy (Road Safety Action Program) [32, p. 29] is oriented to evaluate the possibility to modify existing vehicles with ADAS and implement same systems to newly produced commercial and private vehicles. This action program is set to the year 2020. From technical point of view instalment of highly complex systems into technically older vehicle this process will require accurate installation in order to guarantee correct functionality and reliability.

6. Automation of transportation

Automation of transportation is a widely discussed topic in transportation industry. It represents fast-paced field of modern technology. Automobile companies compete to achieve supremacy over other their competitors in very important field of arising mean of transportation. In California state, USA 62 companies hold a permit for autonomous vehicle trials (with driver) on roads of the state, in a live traffic [33]. The US Society for Automotive Engineers has developed a classification and terminology for automation (*Figure 7*). The levels range from 0, no automation, to full automation, level 5. Each level requires different monitoring of driving environment by driver and if unexpected eventuality happens driver can react or the vehicle itself will employ safety measures.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
***Human driver* monitors the driving environment**						
0	**no Automation**	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**conditional Automation**	The *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**high Automation**	The *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**full Automation**	The full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 8: SAE classification and terminology for vehicle automation [22]

6.1 Benefits of automation

Safety is one of the key issues for automated transportation. As discussed in subchapter 5.4 driver's distraction, inattention, intoxication and inappropriate behaviour on the road, lead up to 95% of all collisions caused by driver error. Continuous progress in development of ADAS and its instalment in vehicles shifts them toward full automation. This will eliminate human error completely and improve safety figures drastically [22].

Increase in mobility is another benefit of autonomous transport. Since vehicles will be controlled by systems, not humans, they will be able to drive at constant speed and maintaining the same distance from the vehicle in front will not be a problem. It is highly probable that this distance will be reduced due to the system's quicker response to unexpected eventualities. This reduction will positively affect flow of the traffic, meaning flow will be much smoother therefore reducing travelling time and length of traffic congestions [34]. Considering capabilities of an autonomous vehicle to drive itself around the town or city, mainly in downtown areas, this can provide the opportunity to free up parking spots. One of the ways to achieve this is to set the vehicle to cruise mode when we need to arrange something in areas with limited parking and it will cruise around the town for necessary amount of time, the vehicle can go to refuel itself (time saving) or it can function as a taxi and make us some money back. After we handle our arrangements, the vehicle will come back and is ready to perform next tasks [34]. Uber and Google companies already announced in February 2015 their intention of having fleet of autonomous vehicles for passenger transportation [35]. Providing transportation for employees and clients throughout the day and at the night serving as a passenger transportation for the public.

6.2 Limitations and possible threats of automated transportation

Despite the benefits discussed above, automated transportation faces several challenges before their successful implementation on the market. Majority of these limitations stem from imperfect perception technology (recognition of relevant objects – recognition between paper bag and a brick for instance, predicting future motion of vehicles, pedestrians, animals and false warnings resulting in spurious braking) [36].

When ADAS was discussed, the purpose of it is to warn the driver who is responsible for the vehicle. In case of an automated vehicle, it has to react and decide on its own. Perception technology in this particular case plays a significant role. A fault of perception technology in ADAS application may have tragic consequences however, the driver can react in time and neutralize the dangerous situation or alleviate consequences of the accident. In a fully automated vehicle, without the driver monitoring the situation, alleviation or avoidance of the collision is improbable. Furthermore, development of perception technology must count on a wide variety of dynamic external hazards, for instance: cyclists, police officers directing the traffic, unsecured load falling off trucks, objects on the road (sand, gravel, debris from previous collisions) and behaviour of other vehicles (traffic laws violation, erratically moving from lane to lane and sirens and lights of law enforcement vehicles) and adapt to current environmental conditions (electromagnetic pulse from lightning, precipitation – rain, hail, mist, fog, snowing, night conditions without illumination, low sun glare angle, snow covered or reflected by wet surface markings and signs on the surface of the road and signs by the road covered by foliage) [36].

"Everything that has software in it is vulnerable to a cyber-attack" says Avi Rubin, computer science professor with area of expertise in computer and information security, in his TEDx talk in Washington DC [37]. This threat also applies to all automated vehicles, as well as other devices, which have system with wireless networking abilities installed in them. Automated vehicles will have these types of systems installed inside of them, therefore security will be an important and essential element in protection of these vehicles against unauthorised users. Rubin [37] mentions an experiment where researchers bought two cars and were able to gain wireless access to all controlling systems (light system, dashboard system, engine control and braking system) and were able to successfully activate, reprogram or disable all of them. The most dangerous threat arises from system fault abuse. This can lead to exploiting these faults and performing all sorts of illegal actions, despite the fact that the system will detect the collision however, it will be disabled. As an example, collision occurring in March 2018 involving Uber self-driving vehicle that struck a jaywalking pedestrian. Official report [38] says that automatic emergency braking system was deliberately disabled to avoid erratic behaviour. The system detected a pedestrian on the road in front of the vehicle six seconds before the accident happened however, it did not alert the driver who was supposed to take an action (he took the action less than second before the accident). On this example it can be seen how tragic the consequences of disabled collision avoidance systems are. The possibility to wirelessly access the vehicle and temper with the system information is high, unless proper security measures are proposed [39].

6.3 Liability for collisions of autonomous vehicles

With regard to Uber self-driving vehicle collision, questions about responsibility for the collision arise. Holding the manufacturer responsible for a collision seems like the most obvious choice, since its product has to drive itself without the driver's interference and manufacturer cannot supply the market with flawed product. An alternative proposed by Hevelke and Nida-Rümelin [40], in their ethical analysis of this problem, is a duty to intervene for the users of autonomous vehicles and holding them responsible for possible collision. This approach defeats the purpose of automated vehicle, since SAE automation table defines the full automation (5th level of automation) as follows: "The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver" [22]. Autonomous vehicles will be able to drive themselves without the presence of any passenger, therefore Hevelke's and Nida-Rümelin's alternative is not possible to apply. Automated and Electric Vehicles Act 2018 [41] delivers new approach to this problem. This Act extends insurance law to cover automated vehicles (vehicle is the driver and human can be sometimes a passenger).

Section 2 sets out the conditions under which the insurer will be liable for damage due to an accident. The conditions are:

a) an accident is caused by an automated vehicle when driving itself on a road or other public place in Great Britain,
b) the vehicle is insured at the time of the accident, and
c) an insured person or any other person suffers damage as a result of the accident. [40]

"Section 5 follows on from the effect of section 2. It emphasises that an insurer involved in a claim would have a right to make a subsequent claim against the manufacturer of the car where that is thought to be the cause of the accident" [40]. Other sections adjust the insurance in case of unauthorized software alternations or failure to update software (the most unique aspect) and limit the liability when the aggrieved party contributes to the cause of the accident. This way the liability is distributed according to an event of accident that happened.

7. Conclusion

Years of technological development in electric transportation delivered strong results in power enhancement, reduction of maintenance and environment sustainability over older internal combustion means of transportation. Despite the technical advantage of electric vehicle and its cost-efficiency, proper utilization in daily using would for its user present rather obligation than benefit with insufficient amount of charging stations, short battery range and slow charging rate. Eliminating these limitations should be main priority for developers and governments, providing them with additional benefits. Therefore, applying further investments, development and involvement from authorities is required to replace internal combustion vehicles with their electric improvement. Process of replacing will definitely take tenths of years, nevertheless, the results, at least in emission reduction will have significant impact on environment, as is proven in third chapter of this thesis.

Propagation and enforcement of advanced driver assistance systems will certainly improve road safety. Systems aimed to prevent the collision or reduce its severity are being tested and their early estimations show great results. One possible benefit of collision avoidance systems to discuss in the future is their cost-efficiency, in other words this system can save money by avoiding collisions and provide more bonuses to insurance for being without collisions.

These technologies markedly contribute to development of automated systems for vehicles, which will be one of the greatest milestones in transportation history and development. Possible benefits it will deliver are safety on the roads, time efficiency, flexibility, smoother traffic flow and possibility to make some money serving as a temporary taxi. As well as in case of electric vehicles, autonomous vehicles are not yet suitable for the implementation to live traffic. Autonomous vehicles have several large technical limitations discussed in the 6^{th} chapter. As they are currently in the testing phase, problems can be easily resolved, and system faults eliminated before full implementation.

Theme for this thesis – New technologies in transportation – has many topics to cover from water, train and aerial transport to hyperloop and space transport. For future work these can be covered and analysed. My bachelor thesis serves as an overview of the newest ground transport technologies, summarize these information, compare and present them.

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